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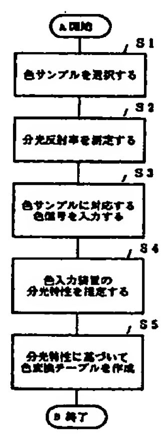
(54) Title: COLOR CONVERSION TABLE CREATING METHOD, COLOR CONVERSION TABLE CREATING DEVICE, AND STORAGE MEDIUM ON WHICH COLOR CONVERSION TABLE CREATING PROGRAM IS RECORDED

(54) 発明の名称: 色変換テーブル作成方法および色変換テーブル作成装置ならびに色変換テーブル作成プログラムを記録した記憶媒体



A ... START
S1 ... SELECT COLOR SAMPLE
S2 ... MEASURE SPECTRAL REFLECTANCE
S3 ... INPUT COLOR SIGNAL CORRESPONDING TO COLOR SAMPLE
S4 ... ESTIMATE SPECTRAL CHARACTERISTICS OF COLOR INPUT DEVICE
S5 ... CREATE COLOR CONVERSION TABLE BASED ON SPECTRAL CHARACTERISTICS
B ... END

(57) **Abstract:** A method for creating a color conversion table used for converting a chrominance signal including characteristics of a color input device to a chrominance signal corresponding to the chromaticity coordinates of another color space, its creating device, and a storage medium on which a color conversion table creating program is recorded. A color sample useful for estimating the spectral input characteristics of a color input device is selected, and a modeling method or a singular value analyzing method using a spline function is used to estimate the spectral input characteristics. As a result, the number of color samples required can be very small, and the spectral input characteristics can be accurately estimated. Many correspondence relationships necessary to create a color conversion table can be established by using a technique for producing a virtual color sample based on the estimated spectral input characteristics or a technique for deriving a color signal from many items of spectral reflectance data.

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VIII-1	Request	4	-
VIII-2	Description	34	-
VIII-3	Claims	7	-
VIII-4	Abstract	1	9902105.txt
VIII-5	Drawings	18	-
VIII-7	TOTAL	64	
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VIII-8	Fee calculation sheet	✓	-
VIII-9	Separate signed power of attorney	✓	-
VIII-10	Copy of general power of attorney	✓	-
VIII-16	PCT-EASY diskette	-	diskette
VIII-17	Other (specified):	Document attaching the revenue stamps equivalent to the fee of payment	-
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Inventor, Patent Number, Country, Author, Title, Name of Document	Issue Date	Concise Explanation of the Relevance (indication of page, column, line, figure of the relevant portion)
a) K. Tanimizu, et al. "PICTURE SIGNAL CORRECTION PROCESSING METHOD," Japanese Patent Laid-Open (Kokai) HEI 6-46252 Laid-Open Date: February 18, 1994		
b) Robert J. Rolleston "COLOR PRINTER CALIBRATION WITH IMPROVED COLOR MAPPING LINEARITY," Japanese Patent Laid-Open (Kokai) HEI 7-307872 Laid-Open Date: November 21, 1995		
b)' Robert J. Rolleston "COLOR PRINTER CALIBRATION WITH IMPROVED COLOR MAPPING LINEARITY," U.S. Patent Number: 5,471,324 Date of Patent: November 28, 1995		This corresponds to above b)
c) J. Odagiri, et al. "A COLOR TRANSFORMATION TABLE CREATING METHOD, A COLOR TRANSFORMATION TABLE CREATING APPARATUS, AND RECORD MEDIUM IN WHICH A COLOR TRANSFORMATION TABLE CREATING PROGRAM IS RECORDED," International Application Number: PCT/JP99/06447 International Filing Date: November 18, 1999		

SPECIFICATION

COLOR TRANSFORMATION TABLE CREATING METHOD, COLOR TRANSFORMATION TABLE CREATING APPARATUS, AND RECORD MEDIUM IN WHICH COLOR TRANSFORMATION TABLE CREATING PROGRAM IS RECORDED

BACKGROUND OF THE INVENTION

Technical Field

The present invention relates to a method for creating a color transformation table used to transform color signals including characteristics of a color input device such as an image scanner or the like into color signals corresponding to chromaticity coordinates in a different color space, a color transformation table creating apparatus in which the above method is used, and a record medium in which a color transformation table creating program is recorded.

When an image on an original is read by a color input device such as an image scanner or the like, a color signal corresponding to each pixel is sometimes transformed into chromaticity coordinates representing an equivalent color in a color system convenient in an image processing by a computer or the like.

At this time, if a color transformation table

having a function of correcting input characteristics of the color input device is prepared as a color transformation table from the RGB color system to the L*a*b* color system, for example, it is possible to obtain chromaticity coordinates showing an absolute color of each pixel in a transforming process using this color transformation table.

Background Art

International Color Consortium (ICC) proposes to represent device characteristics of a color input device such as an image scanner or the like and an output device such as a printer or the like by a profile showing a relationship between a device-dependent color space and a device-independent color space.

This profile is one example of the above-described color transformation table. For example, a profile showing input characteristics of an image scanner is composed of 5000 pairs of a color signal showing coordinates in the RGB color system and chromaticity coordinates in the L*a*b* color space.

Fig. 17 shows an example of a structure of a color transformation managing apparatus.

In the color transformation managing apparatus shown in Fig. 17, an input's side color transforming unit 11 obtains chromaticity coordinates corresponding to a color signal inputted by an image

scanner (hereinafter abbreviated to as a scanner) 17 on the basis of a profile for the scanner stored in a scanner profile storing unit 12, and holds the obtained chromaticity coordinates in a chromaticity coordinates holding unit 13 to provide the chromaticity coordinates to a process by an image processing unit 14.

On the other hand, an output's side color transforming unit 15 again transforms the chromaticity coordinates held in the above-described chromaticity coordinates holding unit 13 into a color signal using a profile for display stored in a display profile storing unit 16, and provides the color signal to a displaying process by a CRT display apparatus 18 (abbreviated as a CRT in the drawing).

With such the color transformation managing apparatus, it is possible to faithfully reproduce colors in an original through the CRT display apparatus 18 irrespective of input characteristics of the scanner 17 and output characteristics of the CRT display apparatus 18, by performing a color transforming process using a profile adapted to the input's side apparatus and a profile adapted to the output's side apparatus.

The profile for scanner and the profile for display described above are created in the following procedure.

For example, when the profile for scanner is created, a standard color chart defined by ISO is read by a scanner that is an object to obtain color signals (P_1-P_n) each showing reflected light intensities of three primary color components from respective regions on the color chart.

Next, chromaticity coordinates (C_1-C_n) showing absolute colors in respective regions on the color chart are measured by a colorimeter or the like, and the chromaticity coordinates are correlated with color signals corresponding to the respective regions as shown in Fig. 18, whereby relationships that become a base of the profile are obtained.

After that, an interpolation operation process is performed on the basis of the relationships that are the base to determine relationships between color signals corresponding to grid points uniformly distributed in the RGB space and chromaticity coordinates showing absolute colors to which the color signals should correspond in the L*a*b* space, whereby the profile is completed.

Heretofore, each time a profile of a scanner is created, 288 colors expressed on the standard color chart are measured as above, an interpolation operation process is performed on the basis of relationships of the obtained 288 pairs, and relationships of 5000 pairs are determined.

As a technique relating to the interpolation operation process, there is a technique of creating a number of relationships in a linear interpolation process on the basis of relationships obtained as measured values, as disclosed in, for example, Japanese Patent Laid-Open Publication No. HEI 7-307872.

On the other hand, there is also proposed a technique of estimating spectral characteristics of a scanner on the basis of relationships obtained as results of measurement, and obtaining relationships configuring a profile by using the obtained spectral characteristics.

As a technique of estimating input characteristics of a color input device such as a scanner or the like, there are proposed various techniques. For example, there is a technique in which simultaneous equations derived on the basis of measured values are solved using the least square method to estimate spectral characteristics, as disclosed in, for example, Japanese Patent Laid-Open Publication No. HEI 6-46252.

However, a work of measuring colors of a number of color samples and a work of reading a number of the color samples by a color input device are essential in both cases where a profile is created by interpolating relationships that become a base, and where a profile is created on the basis of spectral

characteristics estimated from results of measurement.

This work, which needs human labor, counts for a large part of the profile creating work, the time for which is consumed each time a profile is created.

Disclosure of Invention

A main object of the present invention is to provide a technique for creating a color transformation table representing relationships between color signals distributing in a desired distribution in a color space depending on a color input device and chromaticity coordinates representing true colors that these color signals should represent in a desired color space on the basis of results of measurement obtained from a sample set composed of a small number of color samples, thereby decreasing a work of measuring spectral reflectance of color samples and a work of reading the color samples by a scanner that is an object of evaluation, thus largely decreasing a burden of the work as a whole work of creating the color transformation table.

One of subordinate objects of the present invention is to provide a technique for extracting a sample set composed of useful color samples among a number of color samples, thereby improving estimation accuracy at the time that spectral input

characteristics of a color input device are estimated.

A second subordinate object of the present invention is to provide a technique for precisely estimating spectral input characteristics of a color input device on the basis of measured data obtained from a extracted sample set, thereby keeping estimation error accuracy of the spectral input characteristics in spite of a decrease in the number of color samples that are objects of measurement, thus improving accuracy of a color transformation table that should be finally obtained.

A third subordinate object of the present invention is to provide a technique for creating a color transformation table representing relationships between color signals and chromaticity coordinates, thereby obtaining a highly accurate color transformation table.

The main object of this invention is accomplished by, as shown in Fig. 1, selecting a plurality of color samples useful to estimate spectral input characteristics of a color input device that is an object of evaluation among a sufficient number of color samples, measuring spectral reflectance of each of the selected color samples at predetermined wavelength intervals, inputting a color signal representing a color of each of the selected color samples in a color space depending on the color input

device, estimating spectral input characteristics to be obtained when the color input device reads colors of an original on the basis of the spectral reflectance and the color signals obtained from the selected color samples, and creating a color transformation table showing relationships between color signals distributed in a color space depending on the color input device and chromaticity coordinates representing true colors to be represented by the color signals in another color space on the basis of the estimated spectral input characteristics.

The main object of the present invention is accomplished by, as shown in Fig. 2, a color transformation table creating apparatus comprising a selecting means for selecting a sample set composed of a plurality of color samples useful to estimate spectral input characteristics of a color input device that is an object of evaluation among a sufficient number of color samples, a measuring means for measuring spectral reflectance of each of color samples included in the sample set at predetermined wavelength intervals according to a result of the selection by the selecting means, an inputting means for inputting a color signal representing a color of each of color samples included in the sample set in a color space depending on the color input device according to the result of the selection by the selecting means, an

estimating means for estimating spectral input characteristics to be obtained when the color input device reads colors of an original on the basis of the spectral reflectance data and the color signals obtained from the color samples included in the sample set, and a table creating means for creating a color transformation table representing relationships between color signals distributing in a color space depending on the color input device and chromaticity coordinates representing true colors to be represented by the color signals in another color space on the basis of the estimated spectral input characteristics.

According to the color transformation table creating method and the color transformation table creating apparatus of this invention, it is possible to create a desired color transformation table on the basis of spectral reflectance obtained by measuring selected color samples and color signals, thereby largely decreasing a work of measuring colors by a colorimeter and a work of reading color samples by a color input device.

By a work of selecting color samples configuring the above sample set, it becomes possible to select a usable sample set irrespective of a time to create a color transformation table. If such the work of selecting a sample set is carried out only once, it is possible to create a color transformation table

any number of times on the basis of results of measurement on the same sample set.

One of the subordinate objects is accomplished by that the color transformation table creating apparatus of this invention has the selecting means comprising a first extracting means for extracting a plurality of color samples from a sufficient number of color samples, an evaluation index calculating means for calculating an evaluation index for evaluating dependence of each of components corresponding to each characteristic value representing spectral input characteristics that are an object of evaluation for a sample set composed of the extracted color samples, an outputting means for outputting the sample set as a result of selection when it is shown by a value of the evaluation index that each of the color samples included in the sample set has sufficiently high independence, and a repeating means for instructing the first extracting means to extract a new sample set when it is shown by a value of the evaluation index that dependence of each of the color samples included in the sample set is insufficient.

In the color transforming apparatus according to this invention, the adjusting means controls an extracting operation by the first extracting means according to a value of evaluation index obtained by the evaluation index calculating means, thereby

optimizing a sample set that is a collection of color samples, and provide the sample set composed of color samples having appropriate characteristics to a process in the following stage.

One of the above subordinate objects is accomplished by that the color transformation table creating apparatus of this invention has the selecting means comprising a hue evaluating means for evaluating hue of each of a sufficient number of color samples, and a second extracting means for extracting a group of color samples whose evaluation values with respect to hue uniformly distribute on the basis of a result of evaluation by the hue evaluating means.

The color transformation table creating apparatus according to this invention selects color samples on the basis of hue values, thereby selecting color samples highly useful as measurement data used to estimate the spectral input characteristics, which contributes to improvement of estimation accuracy.

A reason of this is that a set of spectral reflectance data obtained from a sample set obtained as above is considered to have characteristics largely different from one another, thus is expected to have high independence of each of components corresponding to each characteristic value representing spectral input characteristics of a color input device.

One of the above subordinate objects is

accomplished by that the color transformation table creating apparatus of this invention has the selecting means comprising a chroma evaluating means for evaluating chroma of each of a sufficient number of color samples, and a third extracting means for extracting a group of color samples whose chroma is evaluated to be high by the chorma evaluating means.

The color transformation table creating apparatus according to this invention selects color samples on the basis of chroma, thereby selecting color samples very useful as measurement data used to estimate the spectral input characteristics. This can improve estimation accuracy of the spectral input characteristics.

A reason of this is that a set of spectral reflectance data obtained from a sample set obtained as above is considered to have its own unique characteristics, thus is expected to have high independence of each of components corresponding to characteristic values representing spectral input characteristics of a color input device.

The second subordinate object is accomplished by that the color transformation table creating apparatus of this invention has the estimating means comprising an equation creating means for creating simultaneous equations expressing a relationship between a color signal and spectral reflectance data

of a corresponding color sample, a deforming means for applying a model representing spectral input characteristics by a linear sum of a plurality of primary spline functions to deform the simultaneous equations, and a first analyzing means for analyzing the simultaneous equations deformed by the deforming means, calculating weights for the plural spline functions to determine the spectral input characteristics.

The color transformation table creating apparatus according to this invention can precisely estimate the spectral input characteristics at each sample point of the above wavelength on the basis of spectral reflectance data and color signals obtained from color samples in a smaller number than the number of samples at wavelengths at which spectral reflectance is measured.

A reason of this is that the number of weights to be calculated by the first analyzing means is determined from the number of spline functions used for a model representing the above spectral input characteristics, and the number of the spline functions can be determined independently of the number of samples at wavelengths at which spectral reflectance is measured.

The second subordinate object is accomplished by that the color transformation table creating apparatus

of this invention has the estimating means comprising an equation creating means for creating simultaneous equations expressing a relationship between a color signal and spectral reflectance data of a corresponding color sample, a singular value analyzing means for applying a method of singular value analyzes to the simultaneous equation to calculate a weight for an appropriate principal component vector, and a characteristics calculating means for determining the spectral input characteristics on the basis of the obtained weight and a corresponding principal component vector.

The color transformation table creating apparatus according to this invention applies a singular value analyzing method in estimation of the spectral input characteristics to precisely estimate the spectral input characteristics at least sample point of the above wavelength on the basis of spectral reflectance data and color signals obtained from color samples in a number smaller than the number of samples at wavelengths at which spectral reflectance is measured.

The second subordinate object is accomplished by that the color transformation table creating apparatus of this invention has the estimating means comprising an equation creating means for creating simultaneous equations expressing a relationship

between a color signal and spectral reflectance data of a corresponding color sample, a singular value analyzing means for applying a method of singular value analyzes to the simultaneous equations to calculate a weight for an appropriate principal component vector, a characteristics calculating means for determining the spectral input characteristics on the basis of the obtained weight and a corresponding principal component vector, and a vector selecting means for selecting only useful principal component vectors on the basis of the weight for each principal component vector calculated by the singular value analyzing means, and providing a relevant principal component vector and a corresponding weight to a process by the characteristics calculating means.

The color transformation table creating apparatus according to this invention selects only useful principal component vectors by the vector selecting means to suppress an effect of noise included in spectral reflectance data and color signals. This can provide highly accurate estimation of the spectral input characteristics.

The third subordinate object is accomplished by that the color transformation table creating apparatus of this invention has the table creating means comprising a color signal creating means for creating a group of color signals having a desired

distribution in a color space depending on a color input device to use the group of color signals as elements of a color transformation table, a sample creating means for calculating backward spectral reflectance data corresponding to a virtual color sample to be given to each of the color signals obtained by the color signal creating means using spectral input characteristics estimated by the estimating means, and a chroma calculating means for determining chromaticity coordinates in a desired color space from each of spectral reflectance data corresponding to the virtual color sample, and using the chromaticity coordinates as a relevant element of the color transformation table.

The color transformation table creating apparatus according to this invention calculates spectral reflectance data of a set of virtual color samples assumed correspondingly to desired color signals using spectral input characteristics of a color input device, and provides them to a process of calculating chromaticitiy coordinates. It is thus possible to determine relationships between a group of color signals having a desired distribution and chromaticity coordinates in a desired color space with approximately uniform accuracy.

The second subordinate object is accomplished by that the color transformation apparatus of this

invention has the table creating means comprising a color signal creating means for creating a group of color signals having a desired distribution in a color space depending on a color input device to use the group of color signals as elements of a color transformation table, a sample creating means for calculating backward spectral reflectance data corresponding to a virtual color sample to be given to each of the color signals obtained by the color signal creating means using spectral input characteristics estimated by the estimating means, and a chroma calculating means for determining chromaticity coordinates in a desired color space from each of spectral reflectance data corresponding to the virtual color sample, and using the chromaticity coordinates as a relevant element of the color transformation table, and the sample creating means comprising a principal component inputting means for inputting a principal component vector determining spectral reflectance of an arbitrary color sample, a weight calculating means for calculating a weight for the principal component vector in order to give spectral reflectance data to a virtual color sample corresponding to each of the group of color signals having a desired distribution on the basis of the principal component vector and spectral input characteristics, a first reflectance calculating means for determining spectral reflectance data of each

of virtual color samples from a weight obtained by the weight calculating means and the principal component vector, and a reflectance correcting means for correcting a negative value included in a set of obtained spectral reflectance data to zero.

The color transformation table creating apparatus according to this invention can replace a process of determining spectral reflectance data corresponding to a virtual color sample with a simple matrix operation on the basis of an arbitrary color signal and spectral input characteristics, using a principal component vector that is a factor determining reflectance of a color sample. The color transformation table creating apparatus of this invention makes correction on spectral reflectance data obtained in the above matrix operation to eliminate an effect of noise, thereby obtaining realistic chromaticity coordinates.

The third subordinate object is accomplished by that the color transformation table creating apparatus of this invention has the table creating means comprises a color signal creating means for creating a group of color signals having a desired distribution in a color space depending on a color input device to use the group of color signals as elements of a color transformation table, a sample creating means for calculating backward spectral reflectance

data corresponding to a virtual color sample to be given to each of the color signals obtained by the color signal creating means using spectral input characteristics estimated by the estimating means, and a chroma calculating means for determining chromaticity coordinates in a desired color space from each of spectral reflectance data corresponding to the virtual color sample, and using the chromaticity coordinates as a relevant element of the color transformation table, the sample creating means comprising a model expression creating means for creating a model expression expressing a model combining an arbitrary color signal and spectral reflectance data of a virtual color sample to be given to said color signal, an inverse matrix calculating means for determining a general inverse matrix of a matrix representing spectral input characteristics of a color input device in the model expression, a second reflectance calculating means for calculating spectral reflectance data of a virtual color sample on the basis of a group of color signals having a desired distribution and the general inverse matrix, and a reflectance correcting means for correcting a negative value included in a set of obtained spectral reflectance data to zero.

Since a general inverse matrix is determined from the above model expression, the color transformation table creating apparatus of this

invention determines a product of a group of color signals having a desired distribution and the general inverse matrix to determine spectral reflectance data corresponding to a virtual color sample. The color transformation table creating apparatus of this invention makes the above correction on the spectral reflectance data obtained in the matrix operation to eliminate an effect of noise, thereby obtaining realistic chromaticity coordinates.

The third subordinate object is accomplished by that the color transformation table creating apparatus has the table creating means comprising a reflectance inputting means for inputting a set of spectral reflectance data of color samples representing a sufficient number of different colors, a color signal calculating means for calculating a color signal representing input data by a color input device to be expected on the basis of each element included in the set of spectral reflectance data and spectral input characteristics estimated by the estimating means, a color signal correcting means for correcting negative values included in a set of obtained color signals to zero, a second chroma calculating means for determining chromaticity coordinates in a desired color space of each element included in the set of spectral reflectance data, and a relationship calculating means for determining

relationships between a group of color signals having a desired distribution in a color space depending on a color input device and chromaticity coordinates representing colors to be represented by the color signals in the desired chroma space on the basis of relationship between a set of chromaticity coordinates given by the second chroma calculating means and a set of color signals corrected by the signal correcting means.

The color transformation table creating apparatus of this invention can obtain color signals equivalent to those obtained by reading a number of the above color samples by a color input device on the basis of inputted spectral reflectance data and estimated spectral input characteristics. Because, the inputted spectral reflectance data corresponds to a number of color samples. The color transformation table creating apparatus of this invention performs the above correcting process on color signals obtained as above to eliminate an effect of noise, thereby obtaining realistic color signals.

When an interpolating process is performed using a known technique after a number of relationships are obtained, it is possible to determine chromaticity coordinates corresponding to color signals distributing in a grid pattern in a color space depending on a color input device with high accuracy,

for example.

The main object is accomplished by making a computer read a record medium storing therein a program making a computer execute a selecting step of selecting a sample set composed of a plurality of color samples useful to estimate spectral input characteristics of a color input device that is an object of evaluation among a sufficient number of color samples, a measuring step of measuring spectral reflectance of each of color samples included in the sample set at predetermined wavelength intervals according to a result of selection obtained at the selecting step, an inputting step of inputting a color signal representing a color of each of the color samples included in the sample set in a color space depending on the color input device according to the result of selection obtained at the selecting step, an estimating step of estimating spectral input characteristics obtained when the color input device reads colors of an original on the basis of spectral reflectance data obtained from each of the color samples included in the sample set and a color signal, and a table creating step of creating a color transformation table representing relationships between color signals distributing in a color space depending on the color input device and chromaticity coordinates representing true colors that the color signals should

represent in another color space on the basis of the estimated spectral input characteristics.

According to the record medium in which a color transformation table program is recorded, it is possible to operate a computer according to the color transformation table creating method of this invention, estimate spectral input characteristics of a color input device on the basis of results of measurement of a sample set composed of a small number of color samples, and create an appropriate color transformation table.

The color transformation table creating method, the color transformation table creating apparatus, and the record medium in which a color transformation table creating program is recorded can be applied to a work of creating not only a profile of a scanner but also color transformation tables for various color input devices.

Note that the essential means for accomplishing the above three subordinate objects can be freely combined to configure a color transformation table creating apparatus. Regardless of how the essential means are combined, it is possible to accomplish the above primary objects.

Brief Description of Drawings

Fig. 1 is a diagram showing a principle of a

color transformation table creating method according to this invention;

Fig. 2 is a principle block diagram of a color transformation table creating apparatus according to this invention;

Fig. 3 is a diagram showing an embodiment of the color transformation table creating apparatus according to this invention;

Fig. 4 is a flow chart illustrating an operation of the color transformation table creating apparatus according to this invention;

Fig. 5 is a diagram illustrating an operation of selecting color samples;

Fig. 6 is a diagram illustrating a spectral characteristics model;

Fig. 7 is a diagram showing an example of spectral reflectance data of a color sample and an example of spectral input characteristics;

Fig. 8 is a diagram showing a detailed structure of a sample creating unit;

Fig. 9 is a diagram illustrating correction of spectral reflectance data;

Fig. 10 is a diagram showing an embodiment 2 of the color transformation table creating apparatus according to this invention;

Fig. 11 is a flow chart illustrating an operation of the color transformation table creating

apparatus;

Fig. 12 is a diagram illustrating an operation of selecting color samples;

Fig. 13 is a diagram showing detailed structures of a singular value analyzing unit and a second sample creating unit;

Fig. 14 is a diagram showing an embodiment 3 of the color transformation table creating apparatus according to this invention;

Fig. 15 is a flow chart illustrating an operation of the color transformation table creating apparatus;

Fig. 16 is a diagram illustrating an operation of creating a color transformation table;

Fig. 17 is a diagram showing an example of a structure of a color transformation managing apparatus as a prior art; and

Fig. 18 is a diagram showing a relationship between the RGB space and the L*a*b* space.

Best Mode for Carrying Out the Invention

[Embodiment 1]

Fig. 3 shows an embodiment of a color transformation table creating apparatus according to this invention. Fig. 4 shows a flow illustratign an operation of the color transformation table creating apparatus.

When a profile for a scanner that is an object of evaluation is created in the color transformation table creating apparatus shown in Fig. 3, a group of spectral reflectance data obtained by a colorimeter 21 is handed to a sample selecting unit 23 through a measurement control unit 22. In the sample selecting unit 23, a reflectance data set composed of reflectance data corresponding to a sample set having appropriate characteristics is selected from the spectral reflectance data, and handed to a spectral characteristics estimating unit 24.

In this case, spectral reflectance of each of regions configuring a standard color chart is measured as a candidate for color sample by the colorimeter 21 (step S11 shown in Fig. 4), held in a spectral data holding unit 31 provided in the sample selecting unit 23, hue and chroma of the relevant color sample are evaluated on the basis of the spectral reflectance data (step S12 shown in Fig. 4), and a result of the evaluation is provided to a process by an extracting unit 33.

The standard color chart includes a sufficient number of candidates for color sample. Therefore, a color analyzing unit 32 evaluates each candidate for color sample on the basis of the spectral reflectance data obtained by measuring the standard color chart by the colorimeter 21, thereby accomplishing functions

of a hue evaluating means to be described in claim 4 and a chroma evaluating means to be described in claim 5.

When candidates for color sample are distributed in the Munsell hue circle as shown in Fig. 5(a), for example, the extracting unit 33 extracts candidates for color sample having a high chroma, then selects such color samples as distributed at equal hue spaces [step S13 shown in Fig. 4, refer to Fig. 5(b)].

As this, the extracting unit 33 operates on the basis of the result of evaluation by the color analyzing unit 32, so as to operate as a second extracting unit to be described in claim 4 and a third extracting unit to be described in claim 5. On the basis of the result of evaluation obtained by the above color analyzing unit 32, it is possible to extract a sample set composed of appropriate color samples, thus to fulfil a function of a selecting means 11 shown in Fig. 2.

At this time, the extracting unit 33 reads the spectral reflectance data corresponding to these color samples from the spectral data holding unit 31, and inputs the data to the spectral characteristics estimating unit 24 (step S14 shown in Fig. 4).

As this, the extracting unit 33 creates a reflectance data set using the spectral reflectance data held in the spectral data holding unit 32, thereby

fulfilling a function equivalent to a measuring means 12 shown in Fig. 2.

When a color of a candidate for color sample is specified by a color number or the like, an evaluation value showing a color of each candidate for color sample is uniquely determined, of course. Accordingly, it is sufficient to extract a color sample on the basis of the evaluation value. In this case, spectral reflectance data of only the extracted color samples is measured by the colorimeter 21, and provided to the process by the spectral characteristics estimating unit 24.

Sample set information composed of information specifying each color sample extracted as above is handed to the measurement control unit 22, and held in the measurement control unit 22. When a color transformation table is created, the measurement control unit 22 controls an operation of the colorimeter 21 on the basis of the sample set information to measure spectral reflectance of only a designated color sample, and directly sends the obtained spectral reflectance data to the spectral characteristics estimating unit 24.

On the other hand, a group of color signals obtained by reading the standard color chart by a scanner 17 are held in a read data holding unit 25. A color signal inputting unit 26 selectively inputs

a color signal set composed of color signals corresponding to the above sample set among these color signals to the spectral characteristics estimating unit 24 (step S15 in Fig. 4).

At this time, the color signal input unit 26 receives the above sample set information from the measurement control unit 22, reads out a color signal corresponding to the designated color sample from the read data holding unit 25, and inputs it to the spectral characteristics estimating unit 24.

As above, the color signal inputting unit 26 operates in response to an instruction from the measurement control unit 22, thereby fulfilling a function of an inputting means shown in Fig. 2.

Responsive to an input of the reflectance data set and the color signal set described above, the spectral characteristics estimating unit 24 performs a process to estimate spectral input characteristics of the scanner 17 with respect to components configuring a color signal.

Here, components (R_j, G_j, B_j) of a color signal corresponding to the j-th color sample are expressed by Expression 1 below, using spectral reflectance $Ref_j(\lambda)$ of this color sample, spectral characteristics $L(\lambda)$ of a light source illuminating the color sample in the scanner 17, and spectral sensitivity characteristics $S_i(\lambda)$ (i = R, G, B) of

sensors S_r, S_g, S_b provided in the scanner 17.

$$R_j=\sum_{\lambda=\lambda_1}^{\lambda_n} L(\lambda)\cdot \mathrm{Re}f_j(\lambda)\cdot S_R(\lambda)$$

$$G_j=\sum_{\lambda=\lambda_1}^{\lambda_n} L(\lambda)\cdot \mathrm{Re}f_j(\lambda)\cdot S_G(\lambda)$$

$$B_j=\sum_{\lambda=\lambda_1}^{\lambda_n} L(\lambda)\cdot \mathrm{Re}f_j(\lambda)\cdot S_B(\lambda)$$

… Expression 1

In this case, the spectral input characteristics of the scanner 17 are expressed by a product $LS_i(\lambda)$ of spectral characteristics $L(\lambda)$ of the light source and spectral sensitivity characteristics $S_i(\lambda)$ of the sensor.

When the spectral characteristics $L(\lambda)$ of the light source is unknown, it is sufficient to substitute color signals and spectral reflectance data obtained from j color samples in the above expression 1, and solve simultaneous equations of RGB components for spectral input characteristic $LS_i(\lambda)$.

Here is applied a model expressing spectral input characteristics $LS_i(\lambda)$ by a linear sum of L spline functions C_k whose peak positions are different from one another.

When nine primary spline functions C_k ($k = 1-9$) as shown in Fig. 6 are used as a set of spline functions, for example, spectral input characteristics $LS_i(\lambda)$ at wavelengths λ ($\lambda = (\lambda_1 - \lambda_n)$) are expressed as shown

by Expression 2, using spline function values Ck (i, λ) (i = R, G, B) discretely expressing values of spline functions corresponding to respective RGB components, and weights W_{ik} by which the respective spline functions should be multiplied.

$$\begin{pmatrix} LS_i(\lambda_1) \\ LS_i(\lambda_2) \\ \vdots \\ LS_i(\lambda_n) \end{pmatrix} = \begin{pmatrix} C_{1\,(i,\,\lambda 1)} & C_{2\,(i,\,\lambda 1)} & \cdots & C_{L\,(i,\,\lambda 1)} \\ C_{1\,(i,\,\lambda 2)} & C_{2\,(i,\,\lambda 2)} & \cdots & C_{L\,(i,\,\lambda 2)} \\ \vdots & \vdots & \ddots & \vdots \\ C_{1\,(i,\,\lambda n)} & C_{2\,(i,\,\lambda n)} & \cdots & C_{L\,(i,\,\lambda n)} \end{pmatrix} \bullet \begin{pmatrix} W_{i1} \\ W_{i2} \\ \vdots \\ W_{i9} \end{pmatrix}$$

… Expression 2

A simultaneous equations creating unit 34 shown in Fig. 3 substitutes the expression 2 for spectral input characteristics $LS_R(\lambda)$ with respect to R component in the expression 1, for example, creates simultaneous equations combining values R_j of R components of the color signals and weights W_{ik} for the nine spline functions, and provides them to a process by a least square analyzing unit 35 shown in Fig. 3 (step S16 in Fig. 4).

$$\begin{pmatrix} R_1 \\ R_2 \\ \vdots \\ R_m \end{pmatrix} = \begin{pmatrix} \sum_{\lambda=\lambda_1}^{\lambda_n} \mathrm{Re}\, f_1(\lambda) \cdot C_{1\,(R,\,\lambda)} & \sum_{\lambda=\lambda_1}^{\lambda_n} \mathrm{Re}\, f_1(\lambda) \cdot C_{2\,(R,\,\lambda)} & \cdots & \sum_{\lambda=\lambda_1}^{\lambda_n} \mathrm{Re}\, f_1(\lambda) \cdot C_{9\,(R,\,\lambda)} \\ \sum_{\lambda=\lambda_1}^{\lambda_n} \mathrm{Rc}\, f_2(\lambda) \cdot C_{1\,(R,\,\lambda)} & \sum_{\lambda=\lambda_1}^{\lambda_n} \mathrm{Re}\, f_2(\lambda) \cdot C_{2\,(R,\,\lambda)} & \cdots & \sum_{\lambda=\lambda_1}^{\lambda_n} \mathrm{Re}\, f_2(\lambda) \cdot C_{9\,(R,\,\lambda)} \\ \vdots & \vdots & \ddots & \vdots \\ \sum_{\lambda=\lambda_1}^{\lambda_n} \mathrm{Re}\, f_n(\lambda) \cdot C_{1\,(R,\,\lambda)} & \sum_{\lambda=\lambda_1}^{\lambda_n} \mathrm{Re}\, f_n(\lambda) \cdot C_{2\,(R,\,\lambda)} & \cdots & \sum_{\lambda=\lambda_1}^{\lambda_n} \mathrm{Re}\, f_n(\lambda) \cdot C_{9\,(R,\,\lambda)} \end{pmatrix} \bullet \begin{pmatrix} W_{R1} \\ W_{R2} \\ \vdots \\ W_{R9} \end{pmatrix}$$

… Expression 3

In this case, a reflectance data set obtained

by measuring spectral reflectance of m color samples at 10 nm intervals within a section from wavelength 380 nm to wavelength 700 nm, and m color signals (R component in this case) obtained by reading the above m color samples by the scanner 17 are substituted in the expression 3, and weights W_{Rk} for respective spline functions are determined, whereby spectral input characteristics $LS_R(\lambda)$ of the scanner 17 are obtained with respect to 36 sample wavelengths at which the spectral reflectance is measured.

Namely, weights for nine spline functions are determined from simultaneous equations with respect to each component of color signals on the basis of a spectral reflectance data set obtained from 24 color samples and a color signal set, for example, whereby values of spectral input characteristics $LS_i(\lambda)$ are obtained with respect to 33 sample wavelengths distributing at 10 nm intervals in a section from wavelength 380 nm to wavelength 700 nm. Thus, the spectral input characteristics $LS_i(\lambda)$ can be precisely estimated.

Since the number of weights to be determined from the simultaneous equations shown in expression 3 is small in this case, it is possible to determine the weights W_{ik} with sufficient accuracy by analyzing the above simultaneous equations by the least square analyzing unit 35 (step S17 in Fig. 4) so long as a

reflectance data set having linear independence in an expectable degree for the reflectance data set.

A characteristics calculating unit 36 shown in Fig. 3 discretely determines values of spectral input characteristics of each component of color signals with respect to sample wavelengths on the basis of the weights obtained as above, and interpolates these discrete values in an appropriate method. As shown in Fig. 7(b), smooth spectral input characteristics (denoted by reference characters R, G and B) of respective color components are thereby estimated (step S18 in Fig. 4).

Namely, the above model is applied to decrease the number of variables to be determined, whereby values of spectral input characteristics can be determined for a sufficient number of sample wavelengths. Thus, smooth spectral input characteristics (denoted by reference characters R, G and B in the drawing) of each color component can be estimated on the basis of these decreased values, as shown in Fig. 7(b).

Spectral characteristics can be estimated on the basis of a small number of results of measurement, which leads to a decrease in burden of the work of measuring spectral reflectance data of each color sample by the colorimeter. Further, it becomes possible to use only useful results of measurement when

spectral input characteristics are estimated, which improves estimation accuracy of the spectral input characteristics as a result.

The spectral reflectance data gently spreads over a wide wavelength range as shown in Fig. 7(a). For this, if it is desired to increase the number of spectral reflectance data composing the reflectance data set, it is obvious that the linear independence of simultaneous equations to be provided to the process by the least square analyzing unit 35 becomes extremely low.

In consequence, that the number of results of measurement necessary to estimate spectral input characteristics is decreased is very useful in consideration of a character of actual color samples.

A profile creating unit 27 shown in Fig. 3 creates a profile on the basis of the spectral input characteristics obtained as above, and the created profile is stored in a profile storing unit 28.

In the profile creating unit 27, a grid data calculating unit 37 corresponds to a color signal creating means to be described in claim 9. For example, the grid data creating unit 37 creates N color signals distributing in a grid pattern appropriately spaced from one another in the RGB color space (step S19 in Fig. 4), and successively stores these color signals in the profile storing unit 28.

The color signals obtained by the grid data calculating unit 37 are handed to a first sample creating unit 38 corresponding to a sample creating means to be described in claim 9. The first sample creating unit 38 calculates spectral reflectance data of virtual color samples to be given to the respective color signals.

A chromaticity coordinates calculating unit 39 shown in Fig. 3 corresponds to a chromaticity calculating means to be described in claim 9. The chromaticity coordinates calculating unit 39 calculates chromaticity coordinates showing a relevant color in the L*a*b* space, for example, on the basis of the spectral reflectance data obtained by the first sample creating unit 38 described above, and stores them correspondingly to a relevant color signal in the profile storing unit 28.

Fig. 8 shows a detailed structure of the profile creating unit.

In the first sample creating unit 38 shown in Fig. 8, a model expression creating unit 41 corresponds to a model expression creating means to be described in claim 11. The model expression creating unit 41 receives discrete spectral input characteristics values $LS_i(\lambda)$ ($\lambda = \lambda_1 - \lambda_n$) from the characteristic value calculating unit 36, and creates a model expression (refer to an expression 4 shown below)

representing a color signal (R, G, B) to be obtained when a color sample is read, using spectral reflectance data Ref(λ) ($\lambda = \lambda_1 - \lambda_n$) of a virtual color sample and a matrix LS having spectral input characteristic values $LS_i(\lambda)$ as elements.

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = (LS) \cdot \begin{pmatrix} \mathrm{Rc}\, f(\lambda_1) \\ \mathrm{Re}\, f(\lambda_2) \\ \vdots \\ \mathrm{Re}\, f(\lambda_n) \end{pmatrix}$$

… Expression 4

By multiplying the both sides of the model expression by a general inverse matrix LS^+ of the matrix LS, the expression 4 is deformed into an expression 5 as shown below. It is obvious that spectral reflectance data Ref(λ) of a virtual color sample corresponding to an arbitrary color signal (R, G, B) can be obtained using the expression 5.

$$LS^+ \cdot \begin{pmatrix} R \\ G \\ B \end{pmatrix} = I \bullet \begin{pmatrix} \mathrm{Re}\, f(\lambda_1) \\ \mathrm{Re}\, f(\lambda_2) \\ \vdots \\ \mathrm{Re}\, f(\lambda_n) \end{pmatrix}$$

… Expression 5

Accordingly, an inverse matrix calculating unit 42 shown in Fig. 8 fulfils a function of an inverse matrix calculating means to be described in claim 11

by determining a general inverse matrix LS^+ of a matrix LS representing spectral input characteristics using an expression 6 shown below.

$$LS^+=(LS^T \cdot LS)^{-1} \cdot LS^T$$

... Expression 6

A reflectance calculating unit 43 shown in Fig. 8 corresponds to a second reflectance calculating means to be described in claim 11. The reflectance calculating unit 43 successively substitutes color signals (R_J, G_J, B_J) (J = 1-N) received from the grid data calculating unit 37 in the expression 5 to calculate spectral reflectance data $Ref_J(\lambda)$ ($\lambda = \lambda_1 - \lambda_n$) corresponding to the color signals (step S20 in Fig. 4).

In Fig. 9, a thin solid line indicates measured reflectance data obtained by measuring spectral reflectance of an actual color sample, whereas a thick solid line indicates estimated reflectance data obtained from a color signal obtained by measuring the color sample by the scanner 17 and estimated spectral input characteristics.

As shown in Fig. 9, it is possible to obtain estimated reflectance data almost equivalent to measured values by means of the above sample creating process.

However, the estimated reflectance data shown in Fig. 9, for example, includes small negative values in a section from wavelength 450 nm to wavelength 500 nm although it is impossible in actuality that spectral reflectance is a negative value.

A reason why such unrealistic values appear in the estimated reflectance data is assumed that an estimated value that should be naturally a positive value very close to zero is negated due to an error caused when a color signal is measured and an error caused when spectral input characteristics are estimated, and an erroneous component appears as a negative value.

For this, a reflectance data correcting unit 44 shown in Fig. 8 performs such correction as to replace a negative value included in the reflectance data obtained as above with zero (step S21 in Fig. 4), and fulfils a function of a reflectance correcting means to be described in claim 11, thereby removing an effect of the measurement error or the estimation error, creating reflectance data more appropriate as reflectance data of a virtual color sample, and providing it to a process by the chromaticity coordinates calculating unit 39.

In response to this, the chromaticity coordinates calculating unit 39 operates to determine appropriate chromaticity coordinates of a color of a

virtual color sample in the L*a*b* space correspondingly to each color signal obtained by the above-described grid data calculating unit 37 (step S22 in Fig. 4).

As this, a set of virtual color samples corresponding to N color signals distributing in the RGB space in a desirable distribution are assumed, whereby estimated spectral input characteristics are directly used to create a profile with high accuracy.

At this time, it is unnecessary to newly measure spectral reflectance or color signals.

It is therefore possible to create relationships of about 5000 pairs required as a profile of the scanner 17 on the basis of measured data of n color samples used in estimation of spectral input characteristics of the scanner 17.

The inventors conducted an experiment to investigate a relationship between the number of color samples used to estimate spectral input characteristics and an estimation error.

Since what should be finally obtained in the color transformation table creating apparatus according to this invention is chromaticity coordinates, a color difference between chromaticity coordinates determined from spectral reflectance calculated using estimated spectral input characteristics and chromaticity coordinates

determined from a measured value was employed as an index to evaluate the estimation error, and an average value of the obtained color differences in 288 color samples configuring the standard color chart was determined.

Fig. 9(b) shows a relationship between the number of color samples and an estimation error obtained in the above experiment.

As shown in Fig. 9(b), even when the number of color samples used to estimate the spectral input characteristics is decreased to 24, the estimation errors were approximately at a constant value.

Namely, the color transformation table creating apparatus according to this invention can create a profile configured with relationships of about 5000 pairs on the basis of results of measurement of selected 24 color samples.

As stated above, the parts shown in Fig. 3 operate to realize the color transformation table creating apparatus which creates a highly-accurate color transformation table on the basis of results of measurement of a small number of color samples in the color transformation table creating method to be described in claim 1.

It is thereby possible to largely decrease a work of measuring spectral reflectance of color samples and a work of reading the color samples by a scanner

that is an object of evaluation, which noticeably decreases a burden of the work as a whole work of creating a color transformation table.

[Embodiment 2]

Fig. 10 shows another embodiment of the color transformation table creating apparatus according to this invention. Fig. 11 shows a flow illustrating an operation of the color transformation table creating apparatus.

The color transformation table creating apparatus shown in Fig. 10 comprises a second sample selecting unit 51, a second spectral characteristics estimating unit 54 and a second profile creating unit 57, which correspond to a selecting means, an estimating means and a table creating means to be described in claim 2.

Spectral reflectance data measured by the colorimeter 21 shown in Fig. 10 is held in the spectral data holding unit 31 through the measurement control unit 22 like the above-described embodiment 1 (step S31 in Fig. 11), and provided to a process by the second sample selecting unit 51.

In the second sample selecting unit 51, a second selecting unit 52 corresponds to a first extracting means to be described in claim 3. The second selecting unit 52 randomly extracts, for example, n color samples among candidates for color sample measured by the

colorimeter 21 (step S32 in Fig. 11), reads out spectral reflectance data corresponding to these color samples from the spectral data holding unit 31, and sends the spectral reflectance data to a sample evaluating unit 53.

In response to this, the sample evaluating unit 53 arranges spectral reflectance data $Ref_j(\lambda)$ ($j = 1-n$, $\lambda = \lambda_1 - \lambda_n$) corresponding to n color samples as elements of a matrix *Ref* representing a reflectance data set corresponding to a sample set composed of the above color samples, as shown in an expression 7 below.

$$\begin{pmatrix} Ref(1,\lambda_1) & Ref(1,\lambda_2) & \cdots & Ref(1,\lambda_n) \\ Ref(2,\lambda_1) & Ref(2,\lambda_2) & \cdots & Ref(2,\lambda_n) \\ \vdots & \vdots & \ddots & \vdots \\ Ref(n,\lambda_1) & Ref(n,\lambda_2) & \cdots & Ref(n,\lambda_n) \end{pmatrix}$$

… Expression 7

Next, the sample evaluating unit 53 applies singular value decomposition to the matrix *Ref* to determine its condition number (step S33 in Fig. 11). The sample evaluating unit 53 then compares the determined condition number with a predetermined threshold value Th_1 to evaluate linear independence of the reflectance data set.

When the condition number is larger than the threshold value (No judgement at step S34 in Fig. 11), the sample evaluating unit 53 operates as a repeating means to be described in claim 3 to determine that the

reflectance data set does not have sufficient linear independence, and instructs the second extracting unit 52 to again extract a sample set (step S35 in Fig. 11).

In response to this, the second extracting unit 52 returns to step S32, and again extracts a sample set.

At this time, the second extracting unit 52 may discard the sample set extracted in prior, and again newly extract one. Alternatively, the second extracting unit 52 may store the sample set [refer to Fig. 12(a)] extracted in prior as shown in Fig. 12(a), extract a predetermined number of color samples from candidates for color sample not included in the sample set, and add them.

The sample evaluating unit 53 repeats an operation of extracting a sample set and an operation of evaluating the sample set. When the conditional number becomes smaller than the above-described threshold value Th_1 (YES judgement at step S34 in Fig. 11), the sample evaluating unit 53 operates as an outputting means to be described in claim 3 to determine that the reflectance data set has sufficient linear independence, and inputs spectral reflectance data corresponding to the extracted sample set to the second spectral estimating unit 54 (step S36 in Fig. 11).

Sample set information about the sample set extracted as above is handed to the measurement control

unit 22 like the embodiment 1, and held in the measurement control unit 22 to be used in a measurement control therafter.

In this case, it is possible to optimize color sample included in a sample set as stated above to select a sample set having high linear independence. It becomes thus possible to assure estimation accuracy at the time that the spectral input characteristics are estimated by a processing unit in the following stage.

In response to an input of the sample set information, the measurement control unit 22 controls an operation of a color signal inputting unit 26 like the embodiment 1 to input a color signal set composed of color signals (R_j, G_j, G_j) (j = 1-n) corresponding to respective color samples indicated by the above sample set information among results of reading by a scanner 17 held in a read data holding unit 25 to the second spectral characteristics estimating unit 54 (step S36 in Fig. 11).

In the second spectral characteristics estimating unit 54 shown in Fig. 10, a simultaneous equations composing unit 55 corresponds to a simultaneous equations creating means to be described in claim 7. The simultaneous equations composing unit 54 composes simultaneous equations combining G components of the color signal set and a reflectance

data set as shown in an expression 8, using spectral input characteristics $LS_i(\lambda)$ (i = R, G, B; $\lambda = \lambda_1 - \lambda_n$), in response to inputs of the color signal set and the reflectance data set *Ref* (step S37 in Fig. 11)

$$\begin{pmatrix} G_1 \\ G_2 \\ \vdots \\ G_n \end{pmatrix} = \begin{pmatrix} Ref(1,\lambda_1) & Ref(1,\lambda_2) & \cdots & Ref(1,\lambda_n) \\ Ref(2,\lambda_1) & Ref(2,\lambda_2) & \cdots & Ref(2,\lambda_n) \\ \vdots & \vdots & \ddots & \vdots \\ Ref(n,\lambda_1) & Ref(n,\lambda_2) & \cdots & Ref(n,\lambda_n) \end{pmatrix} \bullet \begin{pmatrix} LS_{G,\lambda 1} \\ LS_{G,\lambda 2} \\ \vdots \\ LS_{G,\lambda n} \end{pmatrix}$$

… Expression 8

Similarly, the simultaneous equations composing unit 55 composes simultaneous equations for R components and B components of the color signal set, and provides them to a process by a singular value analyzing unit 56.

Fig. 13 shows detailed structures of the singular value analyzing unit and the second sample creating unit.

In the singular value analyzing unit 56 shown in Fig. 13, the singular value decomposing unit 61 corresponds to a singular value analyzing means to be described in claim 7. The singular value decomposing unit 61 applies a singular value decomposing method to the reflectance data set *Ref* to decompose the reflectance data set *Ref* into a regular matrix *U*, a matrix *P* composed of principal component vectors $P(j, \lambda)$ ($j = 1-n$, $\lambda = \lambda_1 - \lambda_n$), and a diagonal matrix *W* having weights W_j ($j = 1-n$) for the principal component vectors

as diagonal elements, as shown in an expression 9.

$$\mathrm{Ref} = U \bullet \begin{pmatrix} W_1 & & & 0 \\ & W_2 & & \\ & & \ddots & \\ 0 & & & W_n \end{pmatrix} \bullet \begin{pmatrix} P_{(1,\lambda 1)} & P_{(2,\lambda 1)} & \cdots & P_{(n,\lambda 1)} \\ P_{(1,\lambda 2)} & P_{(2,\lambda 2)} & \cdots & P_{(n,\lambda 2)} \\ \vdots & \vdots & \ddots & \vdots \\ P_{(1,\lambda n)} & P_{(2,\lambda n)} & \cdots & P_{(n,\lambda n)} \end{pmatrix}$$

... Expression 9

A weight adjusting unit 62 shown in Fig. 13 compares a weight W_j ($j = 1-n$) calculated in the course of the above singular value decomposing process with a threshold value Th_2 to be described later, and adjusts a value of the weight obtained by the singular value decomposing unit 61 on the basis of a result of the comparison.

At this time, the weight adjusting unit 62 first obtains the threshold value Th_2 using a maximum value W_{max} of the weights W_j and significant figures S of the spectral reflectance obtained by the colorimeter 21, as shown by an expression 10.

$$Th_2 = W_{max}/S \qquad \text{... Expression 10}$$

When the weight W_j is smaller than the threshold value Th_2 obtained as above, it can be said that the corresponding principal component vector P (j, λ) is an ineffective principal component vector that does not contribute to the spectral reflectance data.

Therefore, the weight adjusting unit 62 replaces a value of the weight W_j having a value smaller than the above threshold value Th_2, so as to fulfil a vector selecting means to be described in claim 8. The weight adjusting unit 62 can thus eliminate an ineffective main component vector, and provide only effective main component vectors to a process by a second characteristic value calculating unit 63.

In Fig. 13, the second characteristic value calculating unit 63 corresponds to a characteristics calculating means to be described in claim 7. The second characteristic value calculating unit 63 applies a result of the adjustment by the above weight adjusting unit 62 to the expression 9, substitutes the reflectance data set *Ref* expressed by the expression 9 in the simultaneous equations (refer to the expression 8) for each component, and solves the simultaneous equations for spectral input characteristics LS_i to determine spectral input characteristics $LS_i(\lambda)$ (i = R, G, B; $\lambda = \lambda_1 - \lambda_n$) at discrete sample wavelengths λ (step S38 in Fig. 11).

The spectral input characteristics $LS_i(\lambda)$ obtained as above is inputted to a second profile creating unit 57, and provided to a process by a second sample creating unit 58.

A vector extracting unit 64 shown in Fig. 13 receives each result of the comparison between the

threshold value Th_2 and the weight W_j described above from the weight adjusting unit 62, extracts only effective principal component vectors from n principal component vectors obtained by the singular value decomposing unit 61 on the basis of the results of comparison, and inputs them to the second sample creating unit 57. The vector extracting unit 64 can thus fulfil a function of a principal component inputting means to be described in claim 9.

The spectral reflectance data Ref(λ) corresponding to an arbitrary color sample can be expressed by a linear sum of principal component vectors P (j, λ) obtained in the singular value analyzing method as shown by an expression 11.

$$\left(\mathrm{Re}f(\lambda_1)\quad \mathrm{Re}f(\lambda_2)\quad \cdots\quad \mathrm{Re}f(\lambda_n)\right)=\begin{pmatrix} P_{(1,\lambda 1)} & P_{(2,\lambda 1)} & \cdots & P_{(n,\lambda 1)} \\ P_{(1,\lambda 2)} & P_{(2,\lambda 2)} & \cdots & P_{(n,\lambda 2)} \\ \vdots & \vdots & \ddots & \vdots \\ P_{(1,\lambda n)} & P_{(2,\lambda n)} & \cdots & P_{(n,\lambda n)} \end{pmatrix}\bullet\begin{pmatrix} W_1 \\ W_2 \\ \vdots \\ W_n \end{pmatrix}$$

… Expression 11

On the other hand, a relationship shown by an expression 12 is established among a color signal (R, G, B) obtained from the same color sample, spectral reflectance data Ref(λ), and spectral input

characteristics $LS_i(\lambda)$ of the scanner 17.

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} LS_R(\lambda_1) & LS_R(\lambda_2) & \cdots & LS_R(\lambda_n) \\ LS_G(\lambda_1) & LS_G(\lambda_2) & \cdots & LS_G(\lambda_n) \\ LS_B(\lambda_1) & LS_B(\lambda_2) & \cdots & LS_B(\lambda_n) \end{pmatrix} \bullet \left(\mathrm{Re}\,f(\lambda_1) \quad \mathrm{Re}\,f(\lambda_2) \quad \cdots \quad \mathrm{Rc}\,f(\lambda_n) \right)$$

... Expression 12

When the above spectral reflectance data Ref (λ) is expressed by a linear sum of three principal component vectors P_1, P_2 and P_3, the expression 11 is substituted in the expression 12 to be deformed, whereby an expression 13 is obtained. On the basis of the expression 13, weights W_1, W_2 and W_3 corresponding to the three principal component vectors P_1, P_2 and P_3 can be uniquely obtained from an arbitrary color signal (R, G, B).

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} LS_R(\lambda_1) & LS_R(\lambda_2) & \cdots & LS_R(\lambda_n) \\ LS_G(\lambda_1) & LS_G(\lambda_2) & \cdots & LS_G(\lambda_n) \\ LS_B(\lambda_1) & LS_B(\lambda_2) & \cdots & LS_B(\lambda_n) \end{pmatrix} \bullet \begin{pmatrix} P_{(1,\lambda 1)} & P_{(2,\lambda 1)} & P_{(3,\lambda 1)} \\ P_{(1,\lambda 2)} & P_{(2,\lambda 2)} & P_{(3,\lambda 2)} \\ \vdots & \vdots & \vdots \\ P_{(1,\lambda n)} & P_{(2,\lambda n)} & P_{(3,\lambda n)} \end{pmatrix} \bullet \begin{pmatrix} W_1 \\ W_2 \\ W_3 \end{pmatrix}$$

... Expression 13

In this case, a matrix operating unit 64 shown in Fig. 13 multiplies spectral input characteristics $LS_I(\lambda)$ in three rows and n columns by principal component vectors $P(L, \lambda)$ (L = 1-3) in n rows and three columns, and hands a matrix K in three rows and three columns obtained in the matrix operation to a

reflectance calculating unit 65.

The reflectance calculating unit 65 shown in Fig. 13 first substitutes the matrix K received from the matrix operating unit 64 in the right side of the above expression 13, and successively substitutes color signals (R_j, G_j, B_j) received from a grid data calculating unit 37 in the left side of the expression 13, and solves simultaneous equations obtained correspondingly to each color signal for each of the weights W_1, W_2, W_3.

The reflectance calculating unit 65 substitutes the weights W_{j1}, W_{j2}, W_{j3} obtained correspondingly to each color signal in the expression 11, multiplies corresponding principal component vectors $P_L(\lambda)$ by these weights, and calculates spectral reflectance data $Ref_j(\lambda)$ corresponding to each color signal.

As above, the matrix operating unit 64 and the reflectance calculating unit 65 operate in response to inputs of the principal component vectors and the estimated spectral input characteristics, thereby accomplishing functions of a weight calculating means and a first reflectance calculating means to be described in claim 10.

When principal component vectors obtained by the singular value analyzing unit 56 are used, it is possible to estimate spectral reflectance data to be

obtained for a virtual color sample corresponding to each color signal, as stated above.

N spectral reflectance data obtained as above are inputted to a reflectance data correcting unit 44, and the correcting process described in the embodiment 1 is performed, whereby a function of a reflectance correcting means to be described in claim 10 is accomplished, and a realistic value as spectral reflectance data of a virtual color sample can be obtained (step S39 in Fig. 11).

Actually, as compared with a color difference ΔE_1 between chromaticity coordinates P_1 obtained in the case where the estimated reflectance data shown in Fig. 9 is used as it is in the chromaticity coordinates calculating process and chromaticity coordinates P_0 calculated on the basis of measured reflectance data,

a color difference ΔE_2 between chromaticity coordinates P_2 calculated on the basis of corrected estimated reflectance data obtained by adding the above correction and the chromaticity coordinates P_0 is very small as shown in Table 1.

Table 1

	L*	a*	b*	Color difference ΔE from measured value
chromaticity coordinates determined from measured value	40.12	57.96	49.33	
chromaticity coordinates determined from estimated value (before correction)	41.43	56.58	71.68	22.43
chromaticity coordinates determined from estimated value (after correction)	41.74	56.2	47.67	2.91

From the above, it can be said that correction by the above reflectance data correcting unit 44 can largely improve accuracy at the time that spectral reflectance data of a virtual color sample is estimated.

Further, it becomes possible to estimate chromaticity coordinates corresponding to each color signal obtained by the grid data calculating unit 37 with high accuracy.

Accordingly, chromaticity coordinates corresponding to each of the above virtual color samples are determined by the chromaticity coordinates calculating unit 39 in response to an input of the spectral reflectance data, and stored correspondingly to the color signal in the profile storing unit 28 (step 40 in Fig. 11), whereby a highly accurate profile can

be obtained.

[Embodiment 3]

Fig. 14 shows still another embodiment of the color transformation table creating apparatus according to this invention. Fig. 15 shows a flow chart illustratig an operation of the color transformation table creating apparatus.

The color transformation table creating apparatus has a third profile creating unit 71 instead of the first profile creating unit 27 described in the first embodiment.

The first sample selecting unit 23 and the measurement control unit 22 select color samples in the similar manner to steps S11 to S13 shown in Fig. 4 (step S51 in Fig. 15), and spectral reflectance data corresponding to relevant color samples is inputted to the first spectral characteristics estimating unit 24 (step S52 in Fig. 15).

The measurement control unit 22 and the color signal inputting unit 26 operate according to a result of the above selection to selectively input relevant color signals to the first spectral characteristics estimating unit 24 (step S53 in Fig. 15).

In response to this, the first spectral characteristics estimating unit 24 estimates spectral input characteristics of the scanner 17 (step S54 in Fig. 15), and an obtained result of the estimation is

inputted to the third profile creating unit 71.

Fig. 16 shows a diagram illustrating an operation of the third profile creating unit.

In the third profile creating unit 71 shown in Fig. 14, a spectral data accumulating unit 72 corresponds to a reflectance inputting means to be described in claim 10. The spectral data accumulating unit 72 accumulates spectral reflectance data $Refs_j(\lambda)$ ($j = 1-M$, $\lambda = \lambda_1 - \lambda_n$) obtained by measuring M different color samples by the colorimeter 21, and successively inputs the spectral reflectance data $Refs_j(\lambda)$ to a color signal calculating unit 73 and the chromaticity coordinates calculating unit 39 (step S55 in Fig. 15).

In this case, the chromaticity coordinates calculating unit 39 calculates chromaticity coordinates (L^*_j, a^*_j, b^*_j) representing a color of a corresponding color sample in response to an input of each spectral reflectance data $Refs_j(\lambda)$ (step S56 in Fig. 15; refer to Fig. 16), thereby fulfilling a function of a second chromaticity calculating means to be described in claim 12. The chromaticity coordinates calculating unit 39 inputs the chromaticity coordinates to a grid data transforming unit 75.

The color signal calculating unit 73 shown in Fig. 14 corresponds to a color signal calculating means

to be described in claim 12. The color signal calculating unit 73 substitutes each of the spectral reflectance data $Refs_j(\lambda)$ received from the spectral data accumulating unit 72 and the spectral input characteristics $LS_i(\lambda)$ received from the above first spectral characteristics estimating unit 24 in the above expression 12 to calculate a color signal (R_j, G_j, B_j) (j = 1-M) to be obtained when a relevant color sample is read by the scanner 17 (step S57 in Fig. 15; refer to Fig. 16).

There is a possibility that there is a color signal whose component is a negative value among M color signals obtained by the color signal calculating unit 73.

A reason why such a negative value appears is that an estimation error of spectral input characteristics, a measurement error occurring when spectral reflectance data is measured, or the like appears since a value of a relevant component is extremely small. On the other hand, a color signal showing an arbitrary color in the RGB space should have each component whose value is not less than zero.

The color signal correcting unit 74 shown in Fig. 14 replaces a negative value included in each of the inputted color signals (R_j, G_j, B_j) with zero, thereby fulfilling a function of a color signal correcting means to be described in claim 12. The color

signal correcting unit 74 appropriately corrects values of color signals calculated from the relevant spectral reflectance data $Refs_j(\lambda)$ and the spectral input characteristics $LS_i(\lambda)$ (step S58 in Fig. 15; refer to Fig. 16) to obtain a realistic color signal.

Thus, it is possible to derive relationships between M color signals and chromaticity coordinates on the basis of M spectral reflectance data accumulated in the spectral data accumulating unit 72, and provide them as relationships that become a base of a profile to a process by the grid data transforming unit 75 (refer to Fig. 16).

Since information that become a base of the relationships is the spectral reflectance data $Refs_j(\lambda)$ accumulated in the spectral data accumulating unit 72 and the estimated spectral input characteristics $LS_i(\lambda)$, a work of measuring a real color chart by the scanner 17 and the colorimeter 21 is unnecessary when the above M relationships are derived.

The spectral reflectance data accumulated in the spectral data accumulating unit 72 can be used any number of times in a work of creating a profile of the scanner 17. Further, the spectral reflectance data can be used any number of times in a work of creating a profile of another color input device.

So long as a sufficient number of spectral

reflectance data are accumulated in the above spectral data accumulating unit 72, it is possible to obtain a sufficient number of relationships by performing the process at step S55 to step S57 described above.

The spectral reflectance data obtained from selected color samples and color signals are provided to the process of estimating spectral input characteristics as stated above, and the singular value analyzing method is applied in the step of estimating the spectral input characteristics, whereby the spectral input characteristics can be estimated precisely and highly accurately. In consequence, a relationship between a color signal and chromaticity coordinates derived using the spectral input characteristics is expected to have an accuracy equivalent to that of a measured value.

The grid data transforming unit 75 corresponding to a relationship calculating means to be described in claim 12 determines color signals uniformly distributed in a grid pattern in the RGB space and chromiticity coordinates corresponding to these color signals on the basis of relationships derived from accumulated spectral reflectance data using a technique disclosed in, for example, a specification of Japanese Patent Application No. HEI 9-262564 (step S59 in Fig. 15), and stores them in the profile storing unit 28 (refer to Fig. 16).

The color transformation table creating apparatus according to this invention can create a profile with high accuracy.

Industrial Applicability

The color transformation table creating apparatus according to this invention can precisely and highly accurately estimate spectral input characteristics of a color input device on the basis of spectral reflectance data obtained by measuring an extremely small number of color samples and color signals obtained by reading these color samples by the color input device that is an object of evaluation. The color transformation table creating apparatus according to this invention thus can create a color transformation table corresponding to color signals having a desired distribution in a color space depending on the color input device using the obtained spectral input characteristics.

In the known techniques, a work of measuring color samples by man occupies a large part of a work of creating a profile of a color input device such as a color scanner. Use of the color transformation table creating apparatus according to this invention can decrease the number of color samples to be measured. This proves usefulness of this invention.

It is considered that effectiveness of samples

that have been first selected does not change at least for a color input device that is an object of evaluation. For this, it is possible to omit a step of selecting useful color samples when a color transformation table for the same color input device is again created, and use the sample set selected in prior as it is.

This is very useful when a color transformation table for the same color input device is created in every predetermined period in order to evaluate a change with time in performance of the color input device.

CLAIMS

(1) A color transformation table creating method comprising the steps of:

selecting a plurality of color samples useful to estimate spectral input characteristics of a color input device that is an object of evaluation among a sufficient number of color samples;

measuring spectral reflectance of each of said selected color samples at predetermined wavelength intervals;

inputting a color signal representing a color of each of said selected color samples in a color space depending on said color input device;

estimating spectral input characteristics to be obtained when said color input device reads colors of an original on the basis of said spectral reflectance and said color signals obtained from said selected color samples; and

creating a color transformation table showing relationships between color signals distributed in a color space depending on said color input device and chromaticity coordinates representing true colors to be represented by said color signals in another color space on the basis of said estimated spectral input characteristics.

(2) A color transformation table creating apparatus comprising:

a selecting means for selecting a sample set composed of a plurality of color samples useful to estimate spectral input characteristics of a color input device that is an object of evaluation among a sufficient number of color samples;

a measuring means for measuring spectral reflectance of each of color samples included in said sample set at predetermined wavelength intervals according to a result of the selection by said selecting means;

an inputting means for inputting a color signal representing a color of each of color samples included in said sample set in a color space depending on said color input device according to the result of the selection by said selecting means;

an estimating means for estimating spectral input characteristics to be obtained when said color input device reads colors of an original on the basis of said spectral reflectance data and said color signals obtained from the color samples included in said sample set; and

a table creating means for creating a color transformation table representing relationships between color signals distributing in a color space depending on said color input device and chromaticity

coordinates representing true colors to be represented by said color signals in another color space on the basis of said estimated spectral input characteristics.

(3) A color transformation table creating apparatus according to claim 2, wherein said selecting means comprises:

a first extracting means for extracting a plurality of color samples from a sufficient number of color samples;

an evaluation index calculating means for calculating an evaluation index for evaluating dependence of each of components corresponding to each characteristic value representing spectral input characteristics that are an object of evaluation for a sample set composed of said extracted color samples;

an outputting means for outputting said sample set as a result of selection when it is shown by a value of said evaluation index that each of said color samples included in said sample set has sufficiently high independence; and

a repeating means for instructing said first extracting means to extract a new sample set when it is shown by a value of said evaluation index that dependence of each of said color samples included in said sample set is insufficient.

(4) A color transformation table creating apparatus according to claim 2, wherein said selecting means comprises:

a hue evaluating means for evaluating hue of each of a sufficient number of color samples; and

a second extracting means for extracting a group of color samples whose evaluation values with respect to hue uniformly distribute on the basis of a result of evaluation by said hue evaluating means.

(5) A color transformation table creating apparatus according to claim 2, wherein said selecting means comprises:

a chroma evaluating means for evaluating chroma of each of a sufficient number of color samples; and

a third extracting means for extracting a group of color samples whose chroma is evaluated to be high by said chorma evaluating means.

(6) A color transformation table creating apparatus according to claim 2, wherein said estimating means comprises:

an equation creating means for creating simultaneous equations expressing a relationship between a color signal and spectral reflectance data

of a corresponding color sample;

a deforming means for applying a model representing spectral input characteristics by a linear sum of a plurality of primary spline functions to deform said simultaneous equations; and

a first analyzing means for analyzing said simultaneous equations deformed by said deforming means, calculating weights for said plural spline functions to determine said spectral input characteristics.

(7) A color transformation table creating apparatus according to claim 2, wherein said estimating means comprises:

an equation creating means for creating simultaneous equations expressing a relationship between a color signal and spectral reflectance data of a corresponding color sample;

a singular value analyzing means for applying a method of singular value analyzes to said simultaneous equation to calculate a weight for an appropriate principal component vector; and

a characteristics calculating means for determining said spectral input characteristics on the basis of said obtained weight and a corresponding principal component vector.

(8) A color transformation table creating apparatus according to claim 2, wherein said estimating means comprises:

an equation creating means for creating simultaneous equations expressing a relationship between a color signal and spectral reflectance data of a corresponding color sample;

a singular value analyzing means for applying a method of singular value analyzes to said simultaneous equations to calculate a weight for an appropriate principal component vector;

a characteristics calculating means for determining said spectral input characteristics on the basis of said obtained weight and a corresponding principal component vector; and

a vector selecting means for selecting only useful principal component vectors on the basis of said weight for each principal component vector calculated by said singular value analyzing means, and providing a relevant principal component vector and a corresponding weight to a process by said characteristics calculating means.

(9) A color transformation table creating apparatus according to claim 2, wherein said table creating means comprises:

a color signal creating means for creating a

group of color signals having a desired distribution in a color space depending on a color input device to use said group of color signals as elements of a color transformation table;

a sample creating means for calculating backward spectral reflectance data corresponding to a virtual color sample to be given to each of said color signals obtained by said color signal creating means using spectral input characteristics estimated by said estimating means; and

a chroma calculating means for determining chromaticity coordinates in a desired color space from each of spectral reflectance data corresponding to said virtual color sample, and using said chromaticity coordinates as a relevant element of said color transformation table.

(10) A color transformation table creating apparatus according to claim 2, wherein said table creating means comprises:

a color signal creating means for creating a group of color signals having a desired distribution in a color space depending on a color input device to use said group of color signals as elements of a color transformation table;

a sample creating means for calculating backward spectral reflectance data corresponding to

a virtual color sample to be given to each of said color signals obtained by said color signal creating means using spectral input characteristics estimated by said estimating means; and

a chroma calculating means for determining chromaticity coordinates in a desired color space from each of spectral reflectance data corresponding to said virtual color sample, and using said chromaticity coordinates as a relevant element of said color transformation table;

said sample creating means comprises:

a principal component inputting means for inputting a principal component vector determining spectral reflectance of an arbitrary color sample;

a weight calculating means for calculating a weight for said principal component vector in order to give spectral reflectance data to a virtual color sample corresponding to each of the group of color signals having a desired distribution on the basis of said principal component vector and spectral input characteristics;

a first reflectance calculating means for determining spectral reflectance data of each of virtual color samples from a weight obtained by said weight calculating means and said principal component vector; and

a reflectance correcting means for

correcting a negative value included in a set of obtained spectral reflectance data to zero.

(11) A color transformation table creating apparatus according to claim 2, wherein said table creating means comprises:

a color signal creating means for creating a group of color signals having a desired distribution in a color space depending on a color input device to use said group of color signals as elements of a color transformation table;

a sample creating means for calculating backward spectral reflectance data corresponding to a virtual color sample to be given to each of said color signals obtained by said color signal creating means using spectral input characteristics estimated by said estimating means; and

a chroma calculating means for determining chromaticity coordinates in a desired color space from each of spectral reflectance data corresponding to said virtual color sample, and using said chromaticity coordinates as a relevant element of said color transformation table;

said sample creating means comprises:

a model expression creating means for creating a model expression expressing a model combining an arbitrary color signal and spectral

reflectance data of a virtual color sample to be given to said color signal;

an inverse matrix calculating means for determining a general inverse matrix of a matrix representing spectral input characteristics of a color input device in said model expression;

a second reflectance calculating means for calculating spectral reflectance data of a virtual color sample on the basis of a group of color signals having a desired distribution and said general inverse matrix; and

a reflectance correcting means for correcting a negative value included in a set of obtained spectral reflectance data to zero.

(12) A color transformation table creating apparatus according to claim 2, wherein said table creating means comprises:

a reflectance inputting means for inputting a set of spectral reflectance data of color samples representing a sufficient number of different colors;

a color signal calculating means for calculating a color signal representing input data by a color input device to be expected on the basis of each element included in said set of spectral reflectance data and spectral input characteristics estimated by said estimating means;

a color signal correcting means for correcting negative values included in a set of obtained color signals to zero;

a second chroma calculating means for determining chromaticity coordinates in a desired color space of each element included in said set of spectral reflectance data; and

a relationship calculating means for determining relationships between a group of color signals having a desired distribution in a color space depending on a color input device and chromaticity coordinates representing colors to be represented by said color signals in said desired chroma space on the basis of relationships between a set of chromaticity coordinates given by said second chroma calculating means and a set of color signals corrected by said signal correcting means.

(13) A record medium storing therein a program making a computer execute:

a selecting step of selecting a sample set composed of a plurality of color samples useful to estimate spectral input characteristics of a color input device that is an object of evaluation among a sufficient number of color samples;

a measuring step of measuring spectral reflectance of each of color samples included in said

sample set at predetermined wavelength intervals according to a result of selection obtained at said selecting step;

an inputting step of inputting a color signal representing a color of each of said color samples included in said sample set in a color space depending on said color input device according to the result of selection obtained at said selecting step;

an estimating step of estimating spectral input characteristics obtained when said color input device reads colors of an original on the basis of spectral reflectance data obtained from each of said color samples included in said sample set and a color signal; and

a table creating step of creating a color transformation table representing relationships between color signals distributing in a color space depending on said color input device and chromaticity coordinates representing true colors that said color signals should represent in another color space on the basis of said estimated spectral input characteristics.

ABSTRACT

The present invention relates to a color transformation table creating method and apparatus for creating a profile representing relationships between color signals distributing in a desired distribution in a color space depending on a color input device and chromaticity coordinates representing true colors that these color signals should represent in a desired color space, and a record medium in which a color transformation table creating program is recorded.

The color transformation table creating method and apparatus of this invention selects color samples useful to estimate spectral input characteristics of a color input device, and applies a modeling method using spline functions or a singular value analyzing method when the spectral input characteristics are estimated, thereby largely decreasing the number of color samples necessary to estimate the spectral input characteristics, and estimating the spectral input characteristics precisely.

The color transformation table creating apparatus of this invention can create a number of relationships necessary to configure a profile using estimated spectral input characteristics and a method of creating virtual color samples or a method of deriving color signals from a number of spectral

reflectance data.

FIG 1

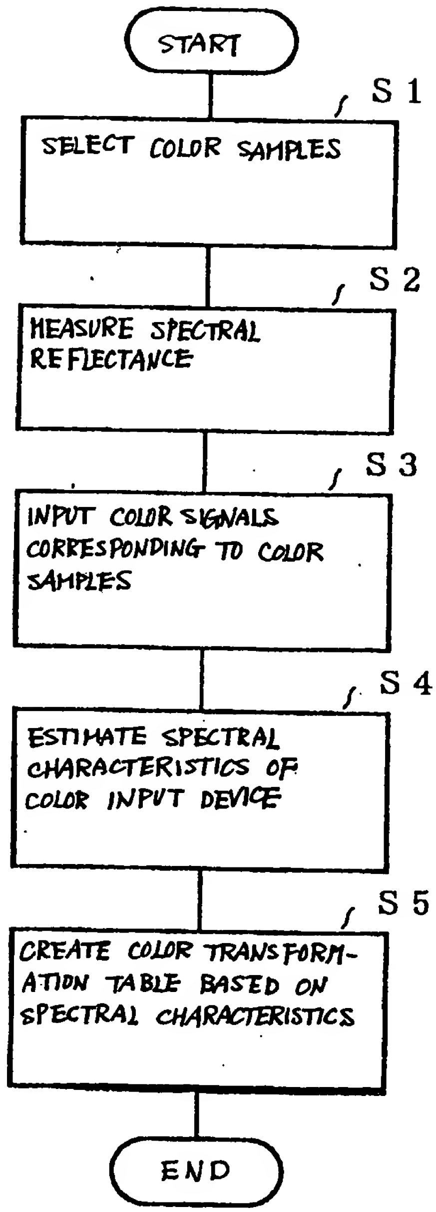
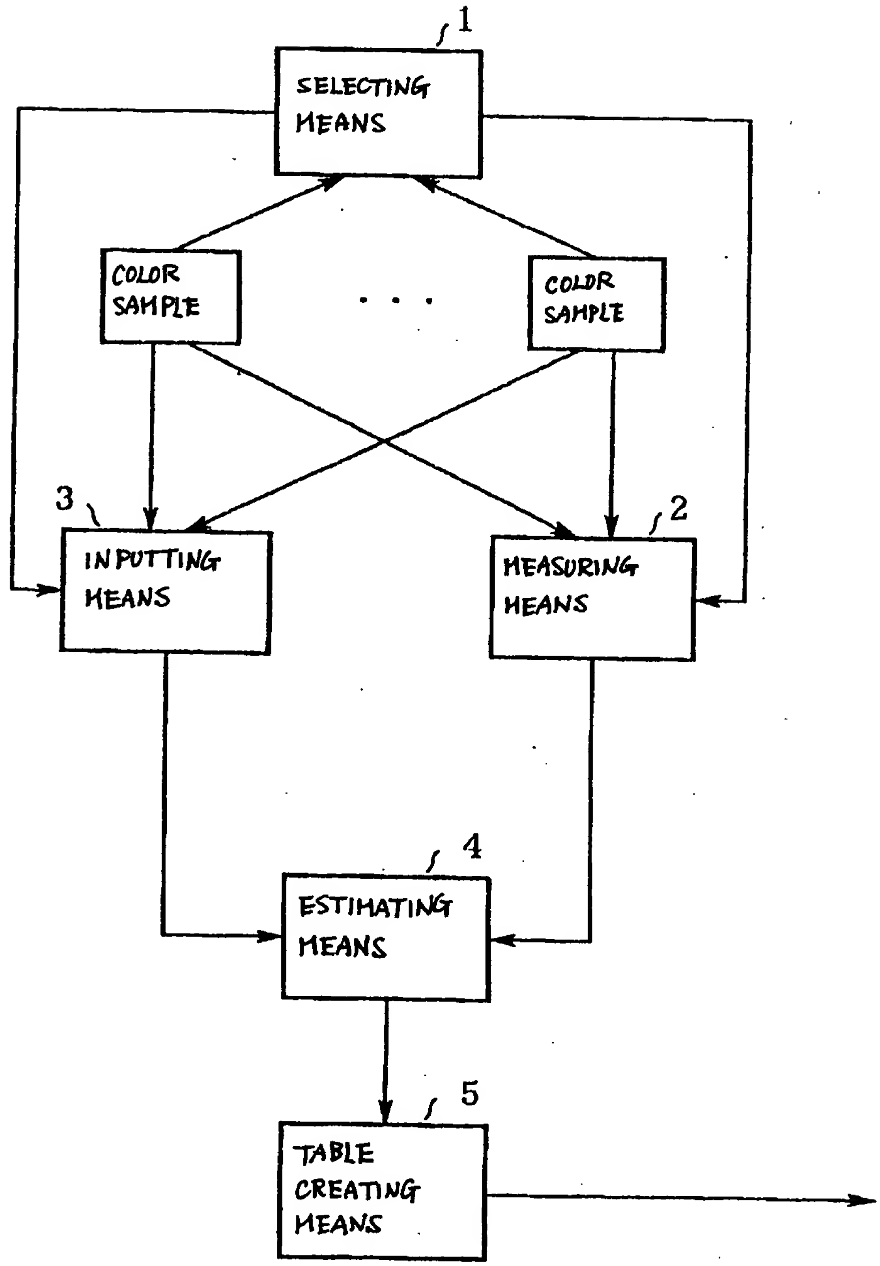

START
S 1
SELECT COLOR SAMPLES
S 2
MEASURE SPECTRAL REFLECTANCE
S 3
INPUT COLOR SIGNALS CORRESPONDING TO COLOR SAMPLES
S 4
ESTIMATE SPECTRAL CHARACTERISTICS OF COLOR INPUT DEVICE
S 5
CREATE COLOR TRANSFORMATION TABLE BASED ON SPECTRAL CHARACTERISTICS
END

FIG 2



1
SELECTING MEANS
COLOR SAMPLE
. . .
COLOR SAMPLE
3
INPUTTING MEANS
2
MEASURING MEANS
4
ESTIMATING MEANS
5
TABLE CREATING MEANS

FIG 3

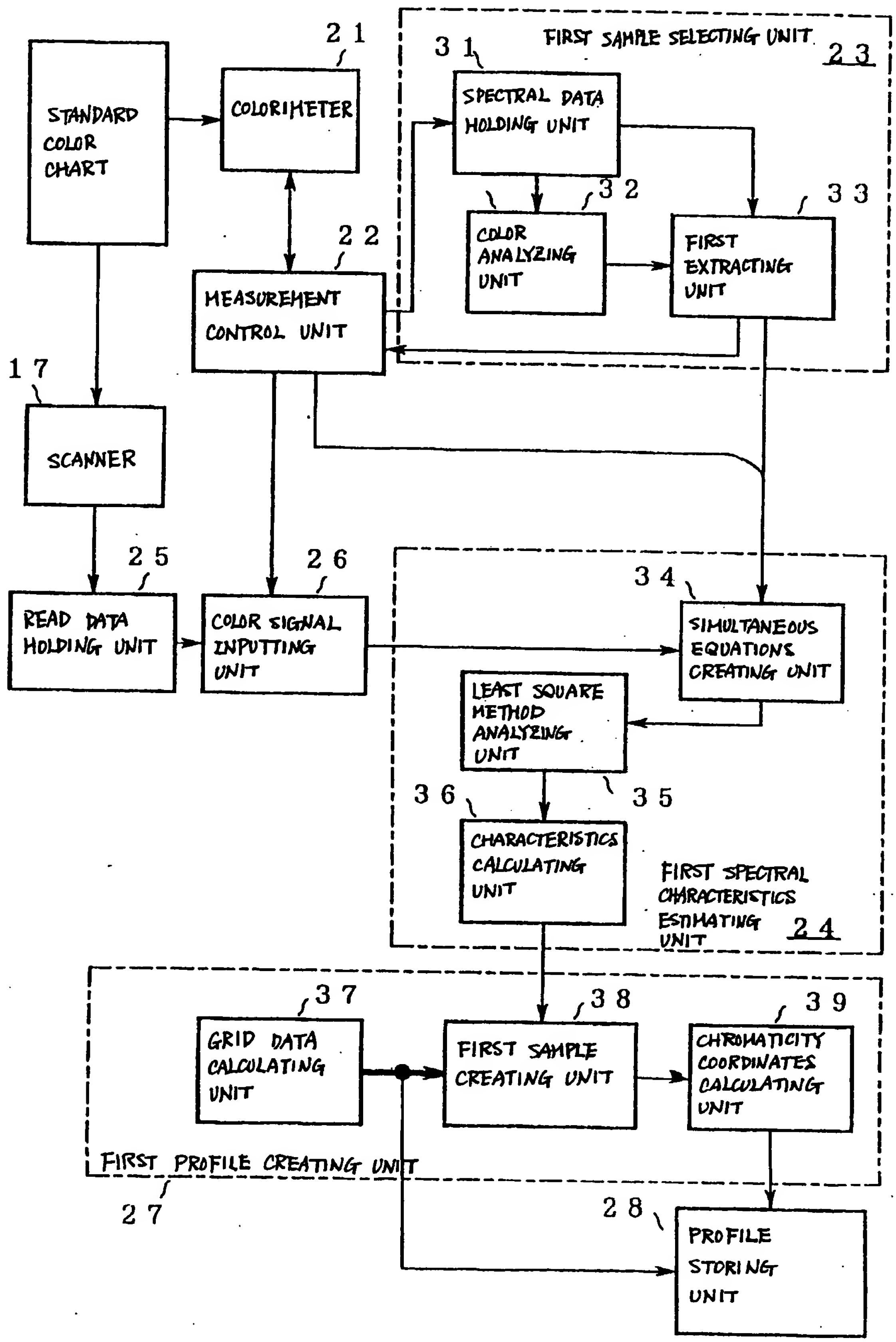

STANDARD COLOR CHART
21
COLORIMETER
FIRST SAMPLE SELECTING UNIT
23
31
SPECTRAL DATA HOLDING UNIT
32
COLOR ANALYZING UNIT
33
FIRST EXTRACTING UNIT
22
MEASUREMENT CONTROL UNIT
17
SCANNER
25
READ DATA HOLDING UNIT
26
COLOR SIGNAL INPUTTING UNIT
34
SIMULTANEOUS EQUATIONS CREATING UNIT
LEAST SQUARE METHOD ANALYZING UNIT
35
36
CHARACTERISTICS CALCULATING UNIT
FIRST SPECTRAL CHARACTERISTICS ESTIMATING UNIT
24
37
GRID DATA CALCULATING UNIT
38
FIRST SAMPLE CREATING UNIT
39
CHROMATICITY COORDINATES CALCULATING UNIT
FIRST PROFILE CREATING UNIT
27
28
PROFILE STORING UNIT

FIG 4

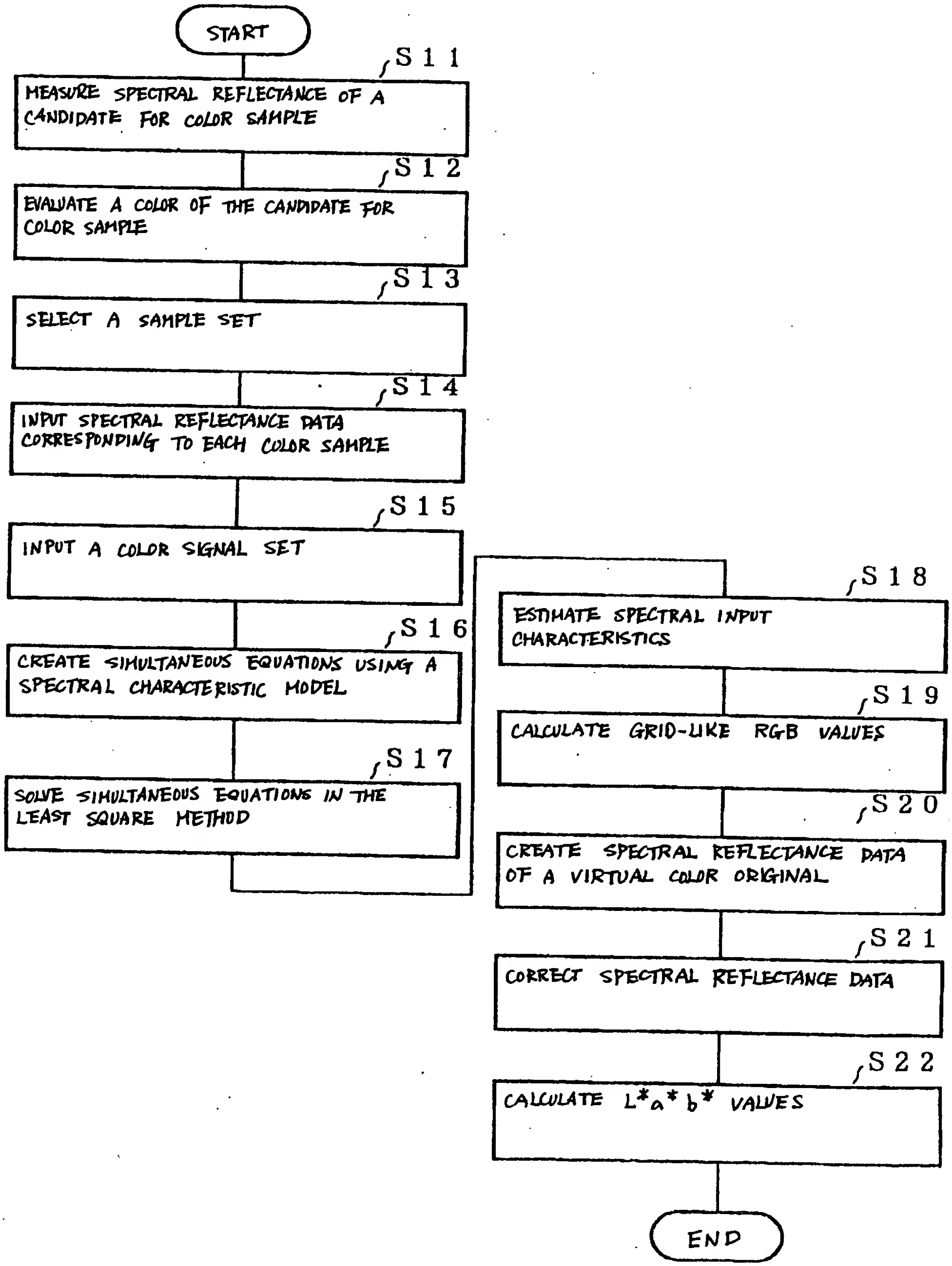
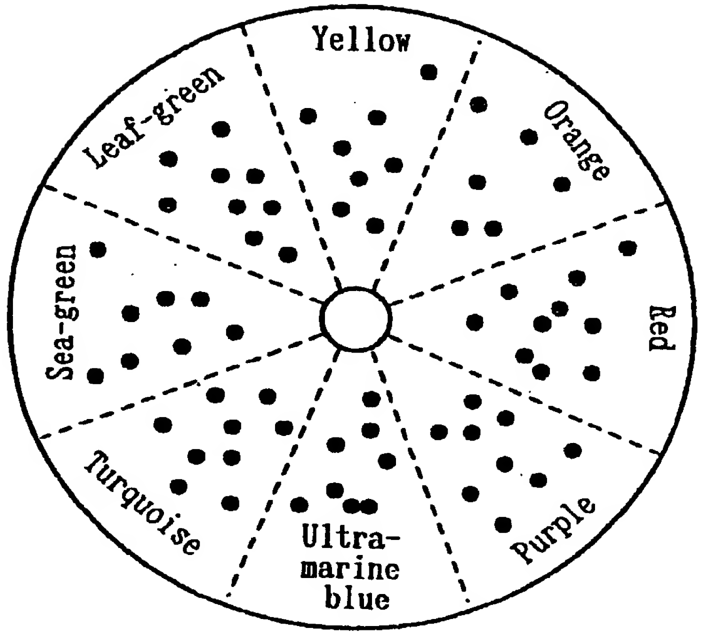

START
S11
MEASURE SPECTRAL REFLECTANCE OF A CANDIDATE FOR COLOR SAMPLE
S12
EVALUATE A COLOR OF THE CANDIDATE FOR COLOR SAMPLE
S13
SELECT A SAMPLE SET
S14
INPUT SPECTRAL REFLECTANCE DATA CORRESPONDING TO EACH COLOR SAMPLE
S15
INPUT A COLOR SIGNAL SET
S16
CREATE SIMULTANEOUS EQUATIONS USING A SPECTRAL CHARACTERISTIC MODEL
S17
SOLVE SIMULTANEOUS EQUATIONS IN THE LEAST SQUARE METHOD
S18
ESTIMATE SPECTRAL INPUT CHARACTERISTICS
S19
CALCULATE GRID-LIKE RGB VALUES
S20
CREATE SPECTRAL REFLECTANCE DATA OF A VIRTUAL COLOR ORIGINAL
S21
CORRECT SPECTRAL REFLECTANCE DATA
S22
CALCULATE L*a*b* VALUES
END

FIG 5

(a)


Yellow
Orange
Red
Purple
Ultra-
marine
blue
Turquoise
Sea-green
Leaf-green

(b)

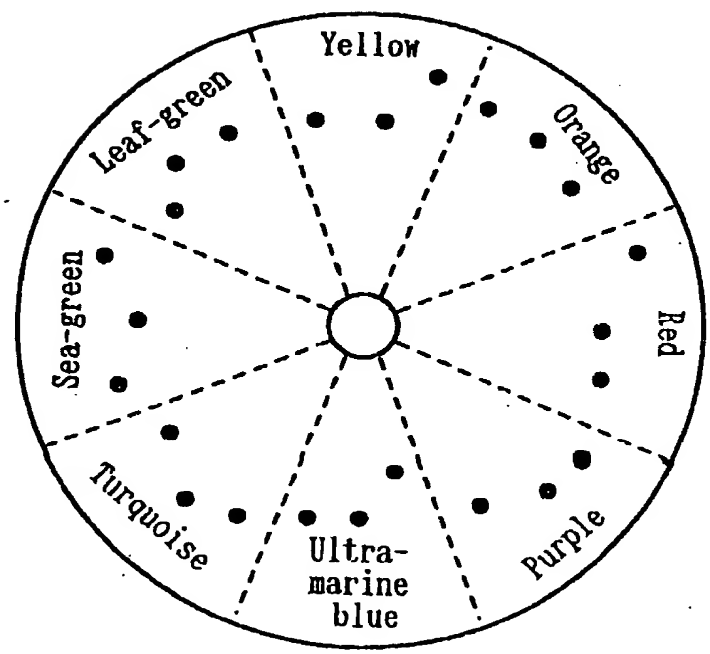

Yellow
Orange
Red
Purple
Ultra-
marine
blue
Turquoise
Sea-green
Leaf-green

FIG 6

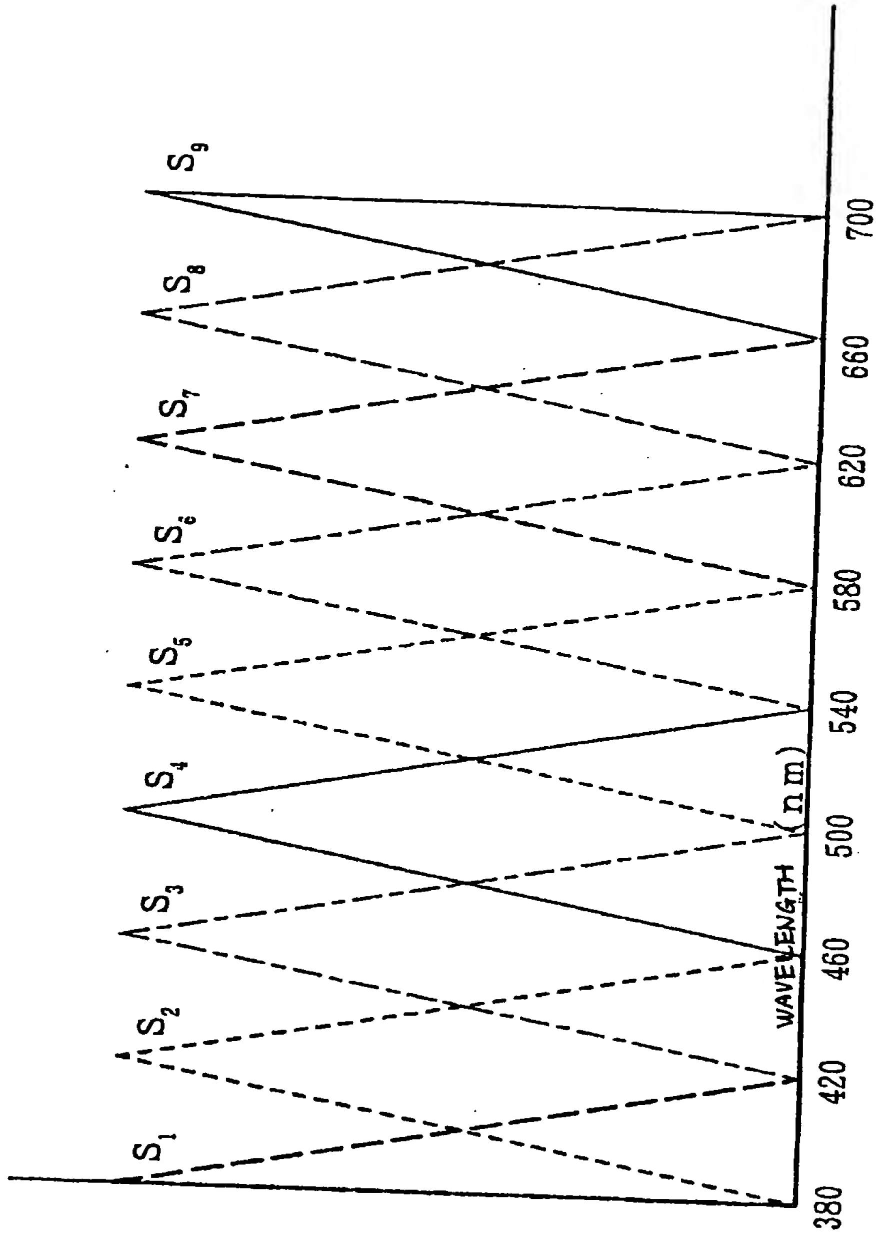
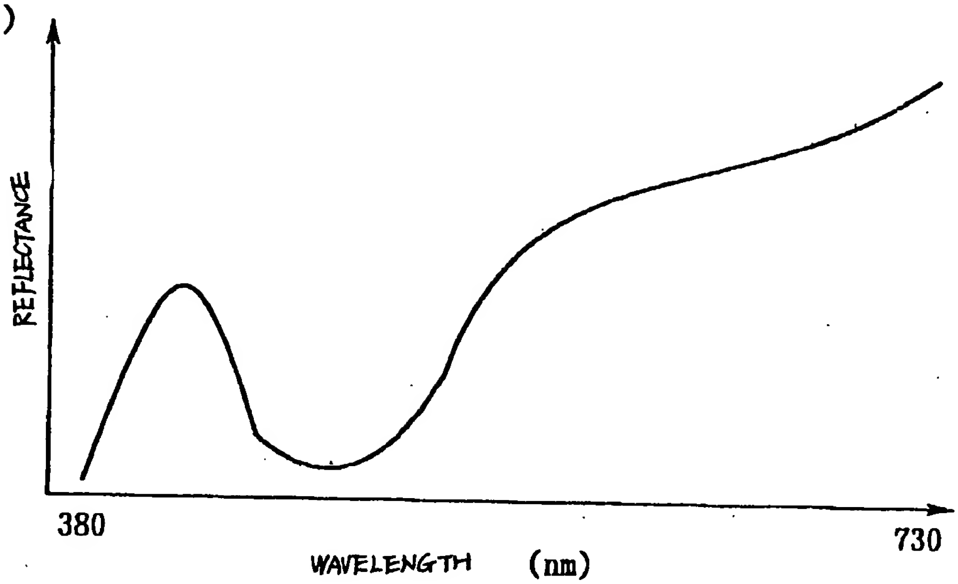

S1
S2
S3
S4
S5
S6
S7
S8
S9
WAVELENGTH (nm)
380
420
460
500
540
580
620
660
700

FIG 7

(a)


REFLECTANCE
380
730
WAVELENGTH (nm)

(b)

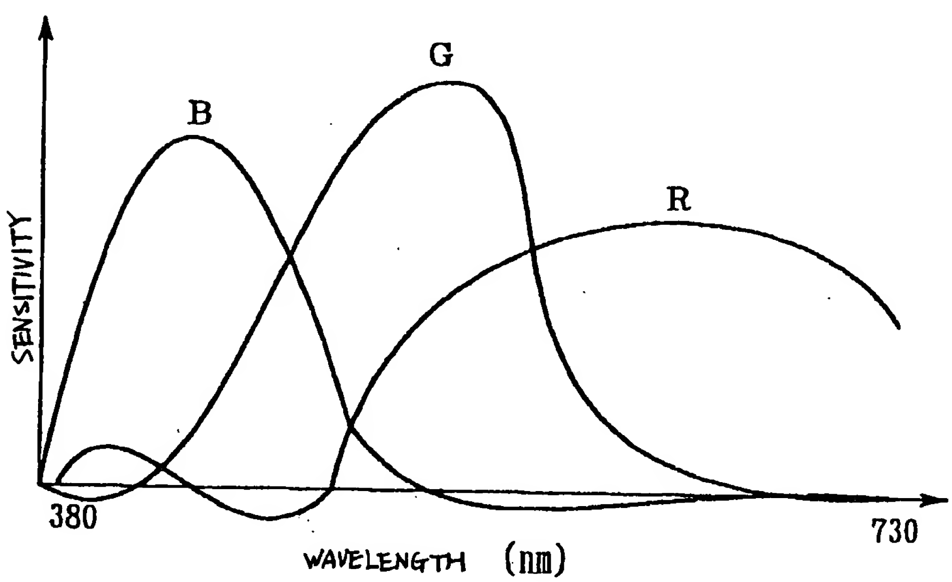

B
G
R
SENSITIVITY
380
730
WAVELENGTH (nm)

FIG 8

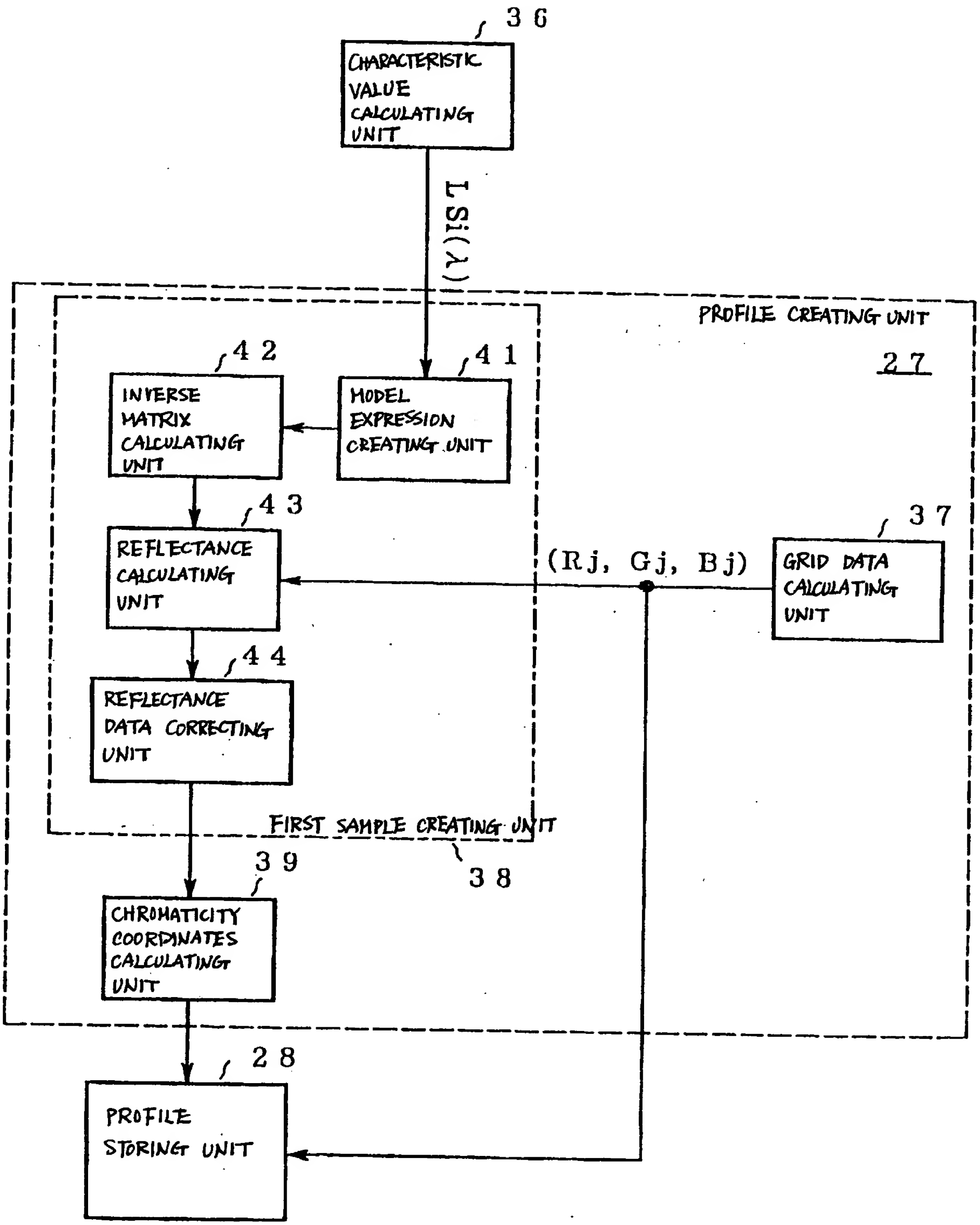
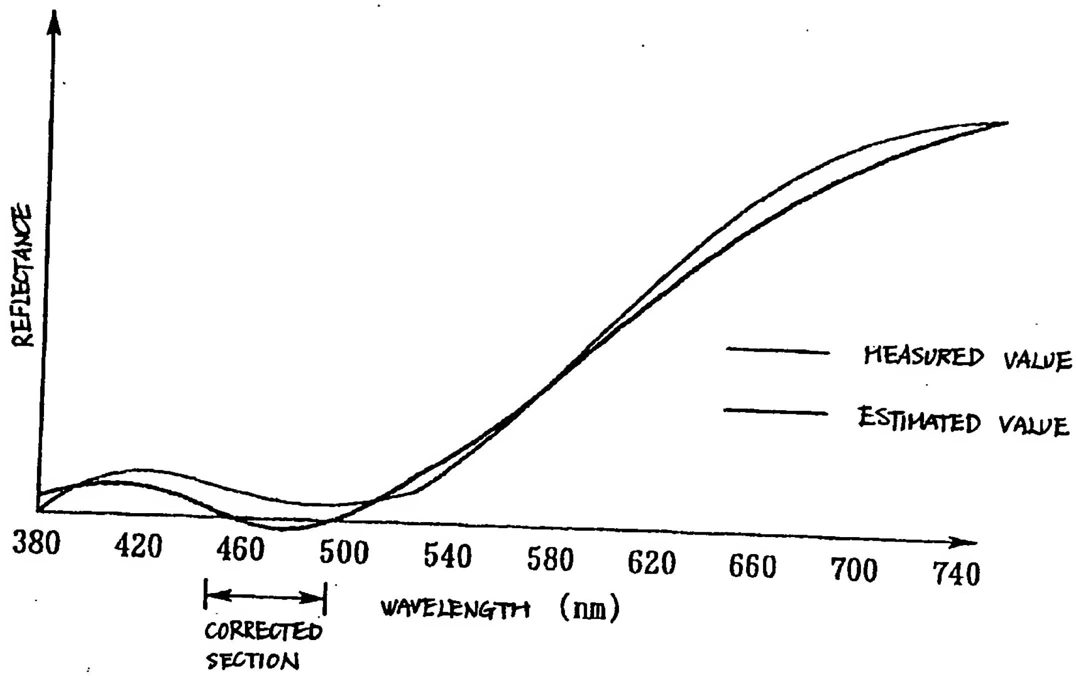

36
CHARACTERISTIC VALUE CALCULATING UNIT
LSi(λ)
PROFILE CREATING UNIT
27
42
INVERSE MATRIX CALCULATING UNIT
41
MODEL EXPRESSION CREATING UNIT
43
REFLECTANCE CALCULATING UNIT
(Rj, Gj, Bj)
37
GRID DATA CALCULATING UNIT
44
REFLECTANCE DATA CORRECTING UNIT
FIRST SAMPLE CREATING UNIT
38
39
CHROMATICITY COORDINATES CALCULATING UNIT
28
PROFILE STORING UNIT

FIG 9

(a)


REFLECTANCE
MEASURED VALUE
ESTIMATED VALUE
380
420
460
500
540
580
620
660
700
740
WAVELENGTH (nm)
CORRECTED SECTION

(b)

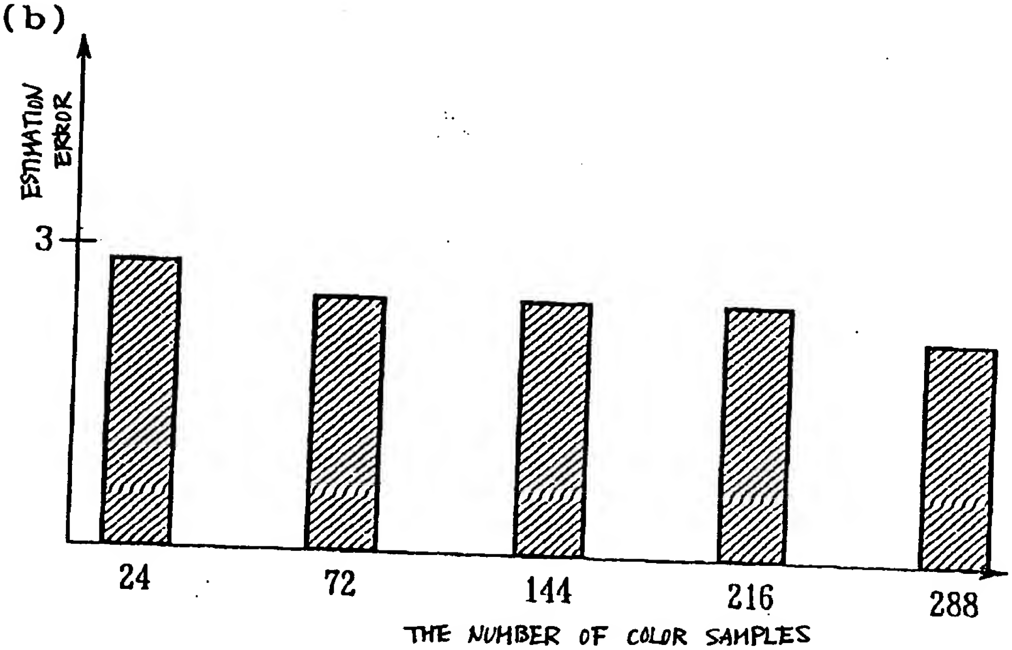

ESTIMATION ERROR
3
24
72
144
216
288
THE NUMBER OF COLOR SAMPLES

FIG 10

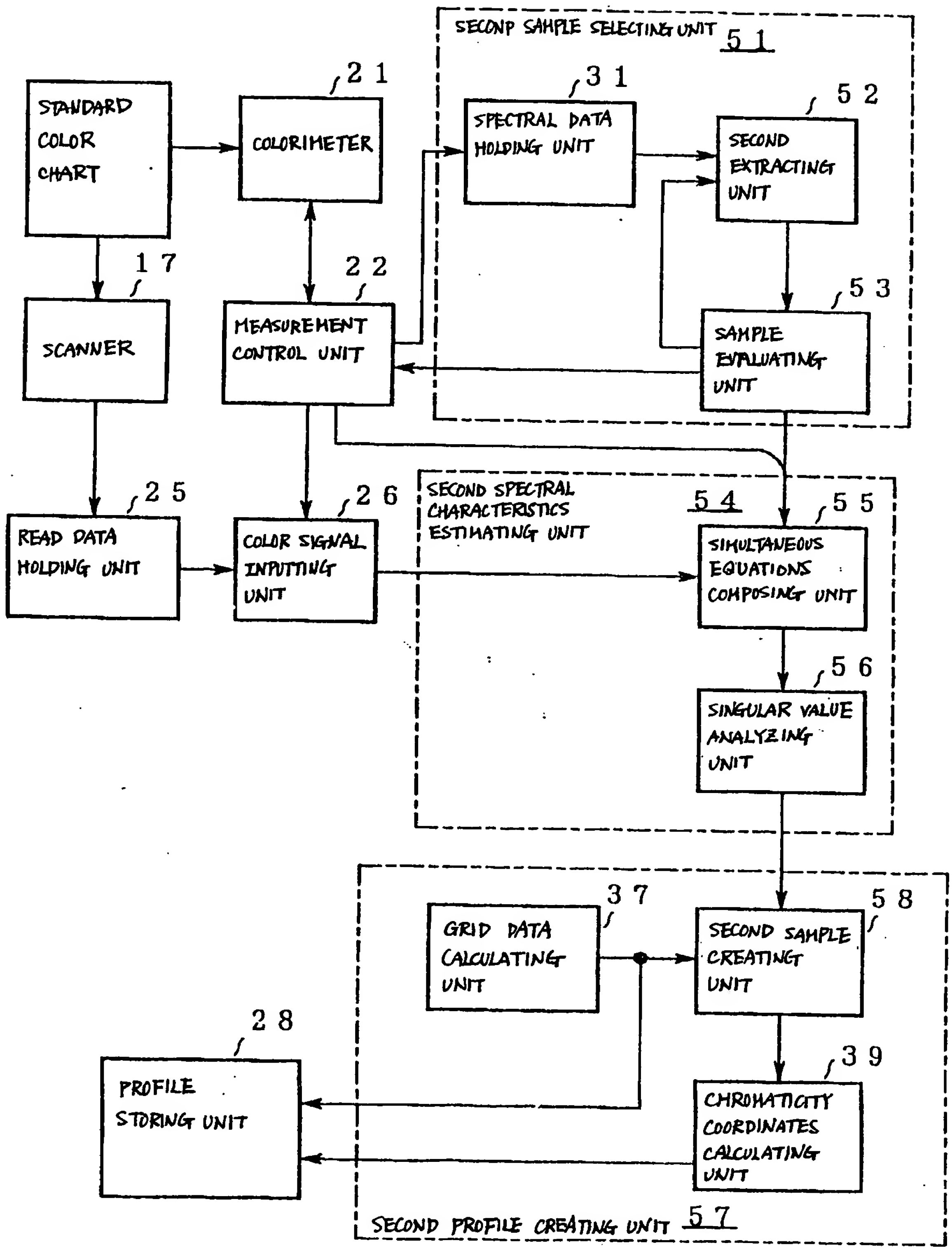

SECONP SAMPLE SELECTING UNIT 51
STANDARD COLOR CHART
COLORIMETER
21
31
SPECTRAL DATA HOLDING UNIT
52
SECOND EXTRACTING UNIT
17
22
53
SCANNER
MEASUREMENT CONTROL UNIT
SAMPLE EVALUATING UNIT
SECOND SPECTRAL CHARACTERISTICS ESTIMATING UNIT
54
55
25
26
READ DATA HOLDING UNIT
COLOR SIGNAL INPUTTING UNIT
SIMULTANEOUS EQUATIONS COMPOSING UNIT
56
SINGULAR VALUE ANALYZING UNIT
37
58
GRID DATA CALCULATING UNIT
SECOND SAMPLE CREATING UNIT
28
39
PROFILE STORING UNIT
CHROMATICITY COORDINATES CALCULATING UNIT
SECOND PROFILE CREATING UNIT 57

FIG 11

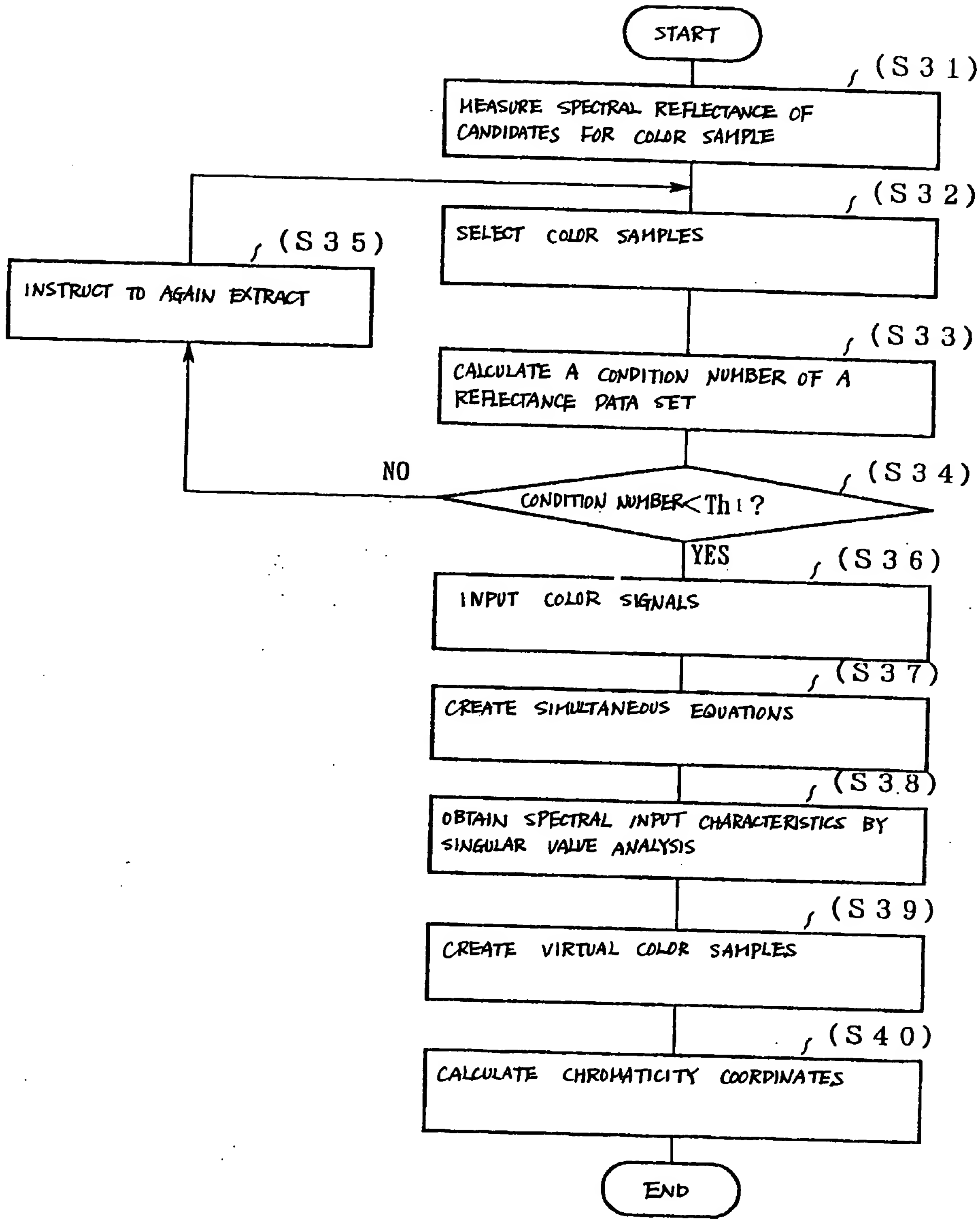
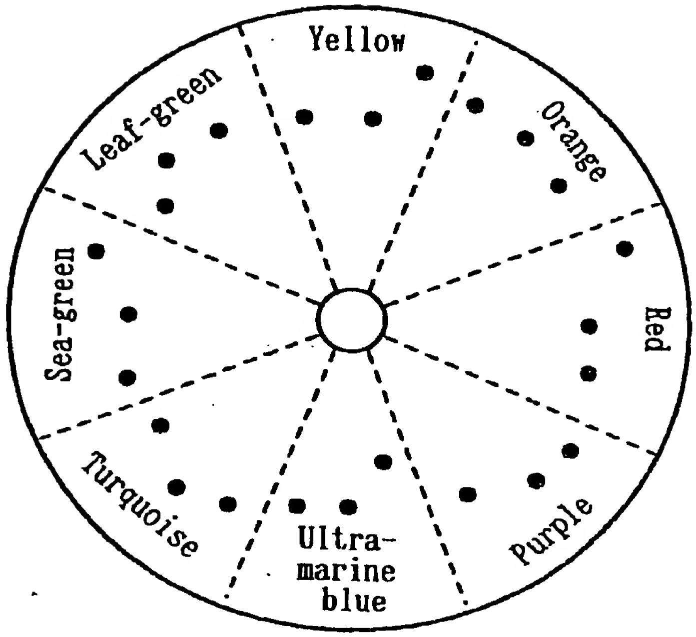

START
(S31)
MEASURE SPECTRAL REFLECTANCE OF CANDIDATES FOR COLOR SAMPLE
(S32)
SELECT COLOR SAMPLES
(S35)
INSTRUCT TO AGAIN EXTRACT
(S33)
CALCULATE A CONDITION NUMBER OF A REFLECTANCE DATA SET
NO
(S34)
CONDITION NUMBER<Th1 ?
YES
(S36)
INPUT COLOR SIGNALS
(S37)
CREATE SIMULTANEOUS EQUATIONS
(S38)
OBTAIN SPECTRAL INPUT CHARACTERISTICS BY SINGULAR VALUE ANALYSIS
(S39)
CREATE VIRTUAL COLOR SAMPLES
(S40)
CALCULATE CHROMATICITY COORDINATES
END

FIG 12

(a)


Yellow
Orange
Red
Purple
Ultra-
marine
blue
Turquoise
Sea-green
Leaf-green

(b)

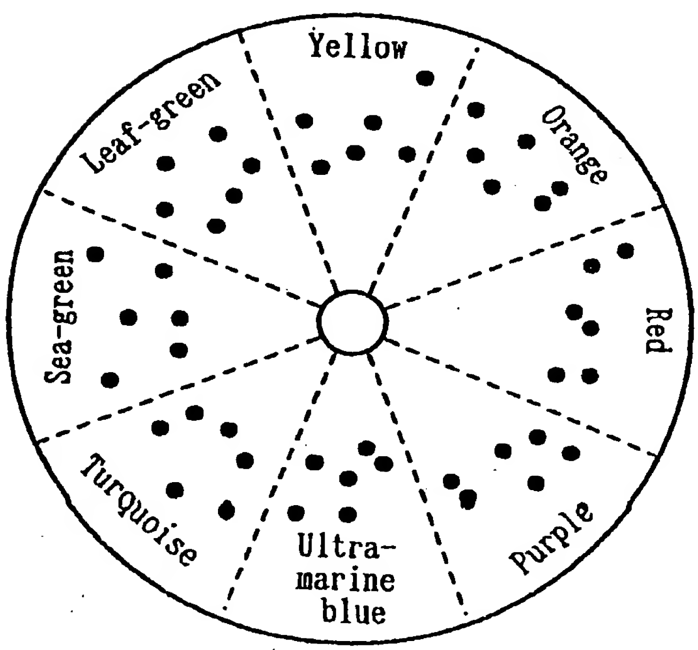

Yellow
Orange
Red
Purple
Ultra-
marine
blue
Turquoise
Sea-green
Leaf-green

FIG 13

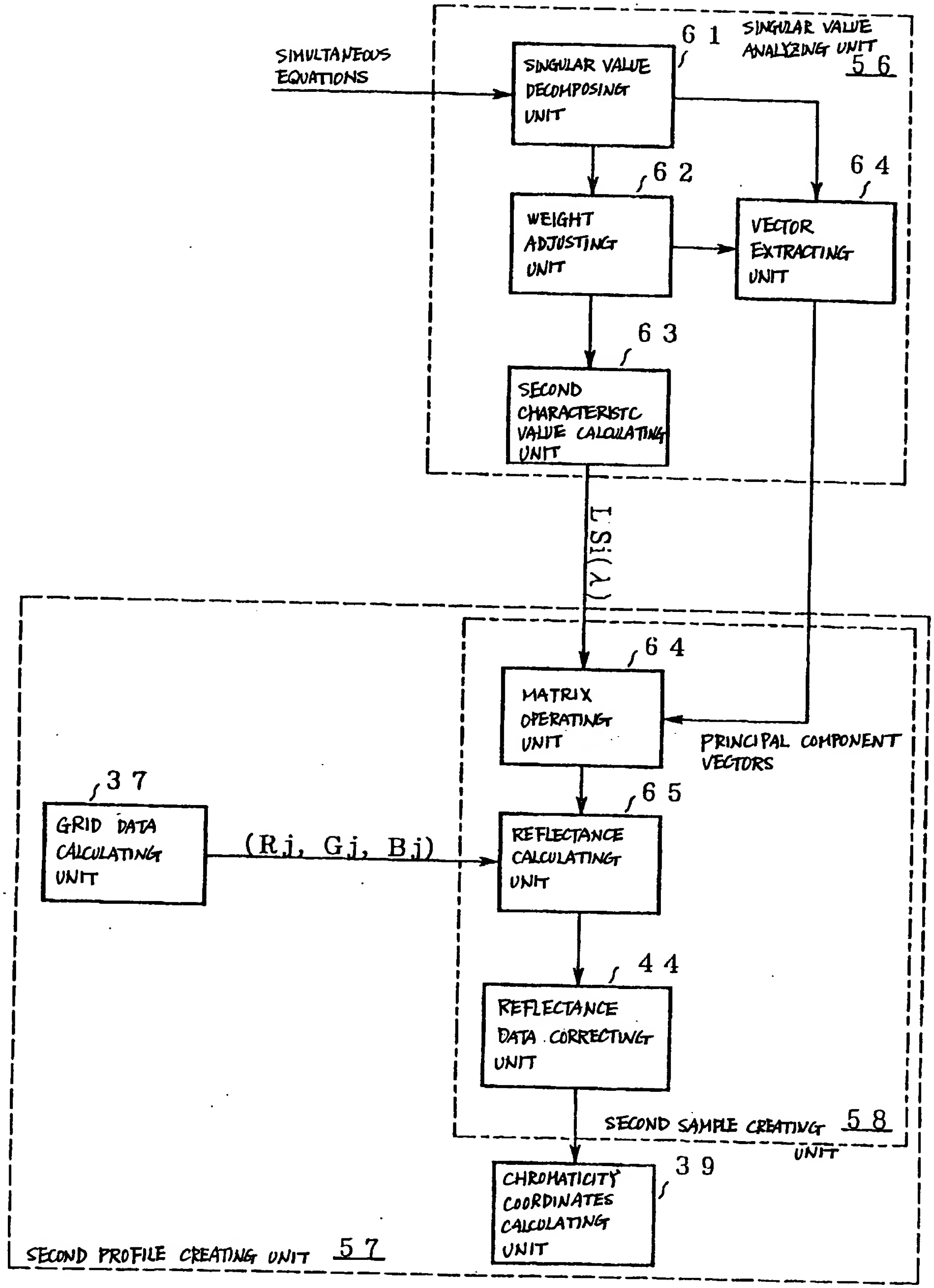
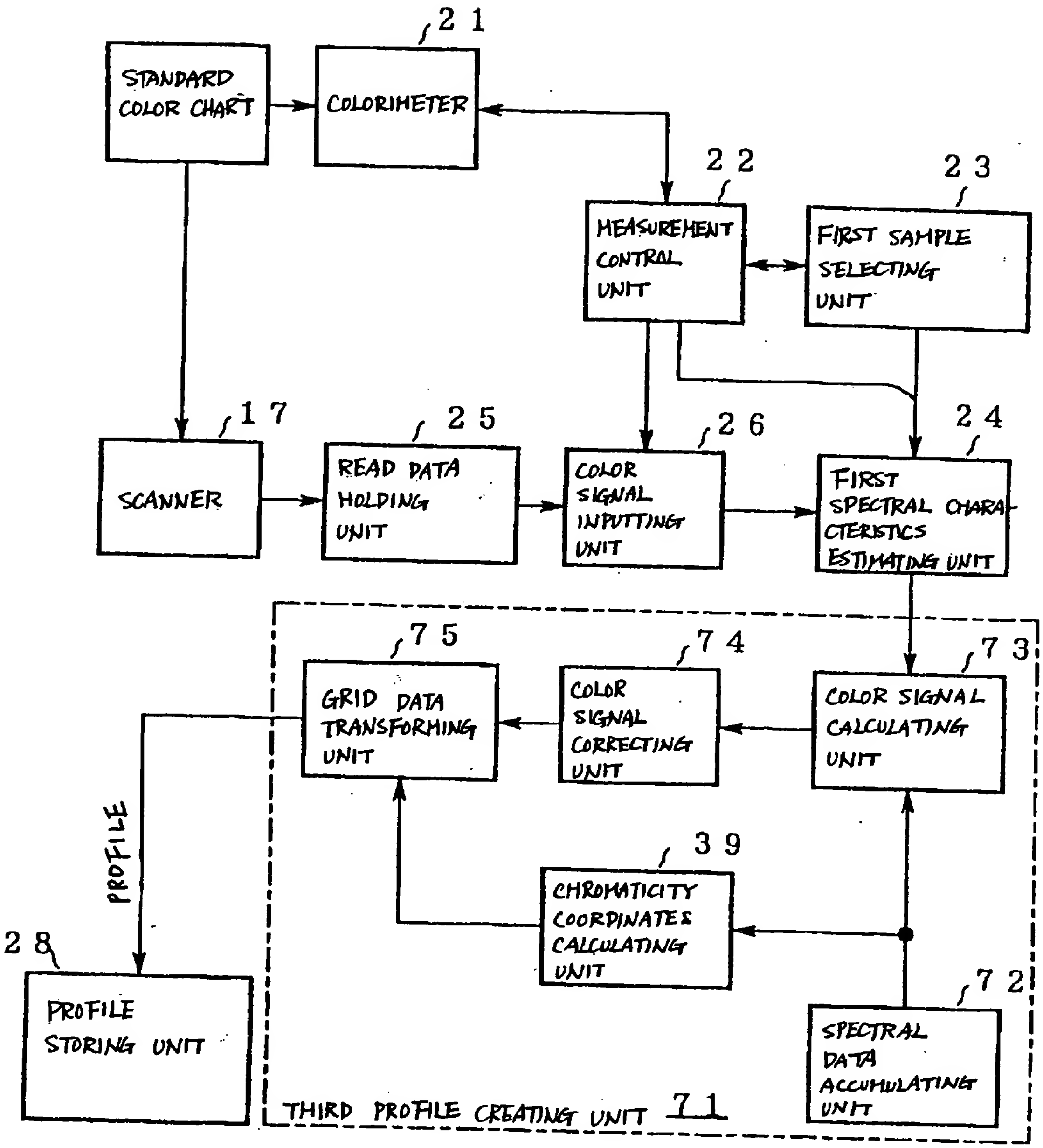

SIMULTANEOUS EQUATIONS
SINGULAR VALUE ANALYZING UNIT 56
61
SINGULAR VALUE DECOMPOSING UNIT
62
WEIGHT ADJUSTING UNIT
64
VECTOR EXTRACTING UNIT
63
SECOND CHARACTERISTC VALUE CALCULATING UNIT
LSi(λ)
64
MATRIX OPERATING UNIT
PRINCIPAL COMPONENT VECTORS
37
GRID DATA CALCULATING UNIT
(Rj, Gj, Bj)
65
REFLECTANCE CALCULATING UNIT
44
REFLECTANCE DATA CORRECTING UNIT
SECOND SAMPLE CREATING UNIT 58
39
CHROMATICITY COORDINATES CALCULATING UNIT
SECOND PROFILE CREATING UNIT 57

FIG 14



STANDARD COLOR CHART
COLORIMETER
21
MEASUREMENT CONTROL UNIT
22
FIRST SAMPLE SELECTING UNIT
23
SCANNER
17
READ DATA HOLDING UNIT
25
COLOR SIGNAL INPUTTING UNIT
26
FIRST SPECTRAL CHARACTERISTICS ESTIMATING UNIT
24
GRID DATA TRANSFORMING UNIT
75
COLOR SIGNAL CORRECTING UNIT
74
COLOR SIGNAL CALCULATING UNIT
73
CHROMATICITY COORDINATES CALCULATING UNIT
39
SPECTRAL DATA ACCUMULATING UNIT
72
PROFILE
PROFILE STORING UNIT
28
THIRD PROFILE CREATING UNIT 71

FIG 15

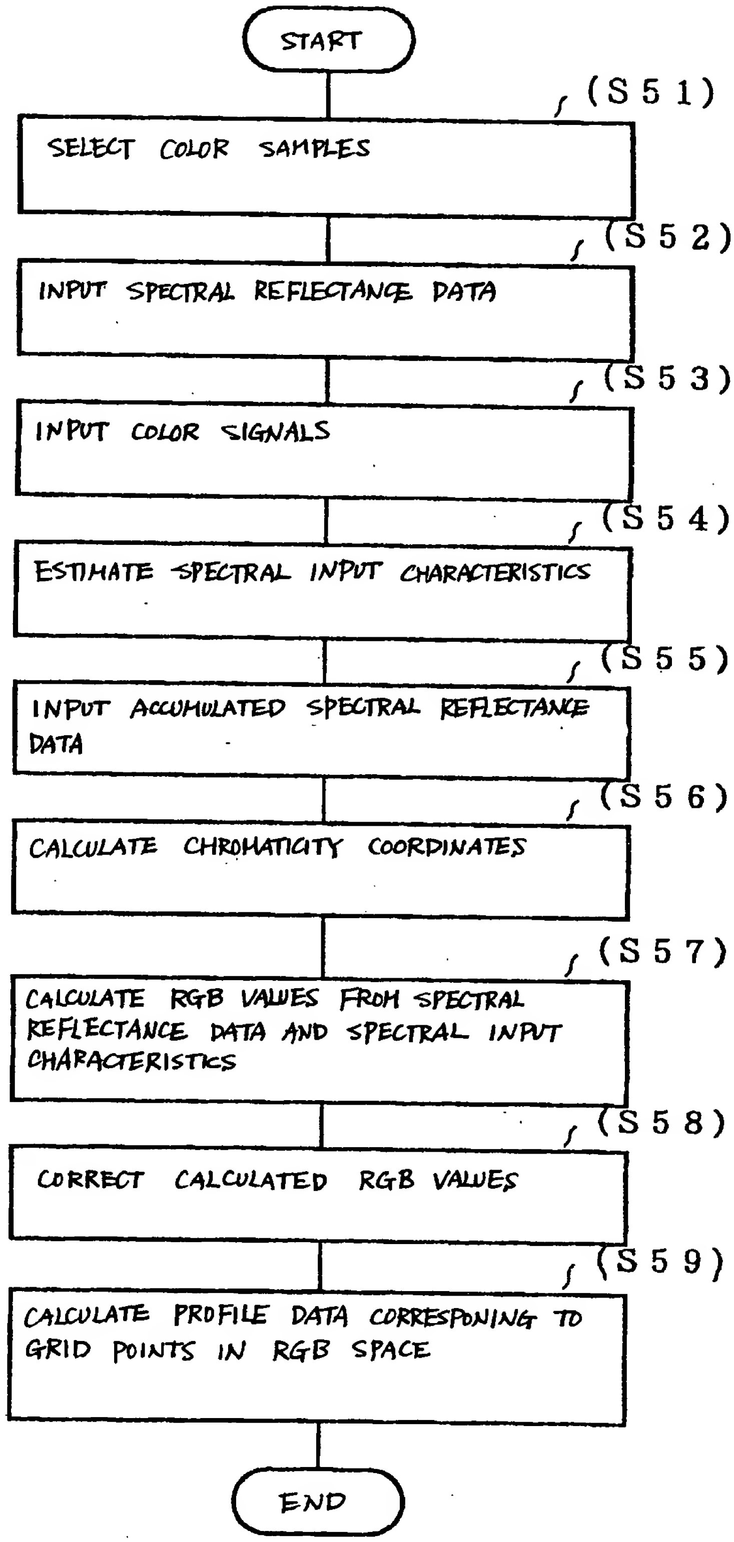
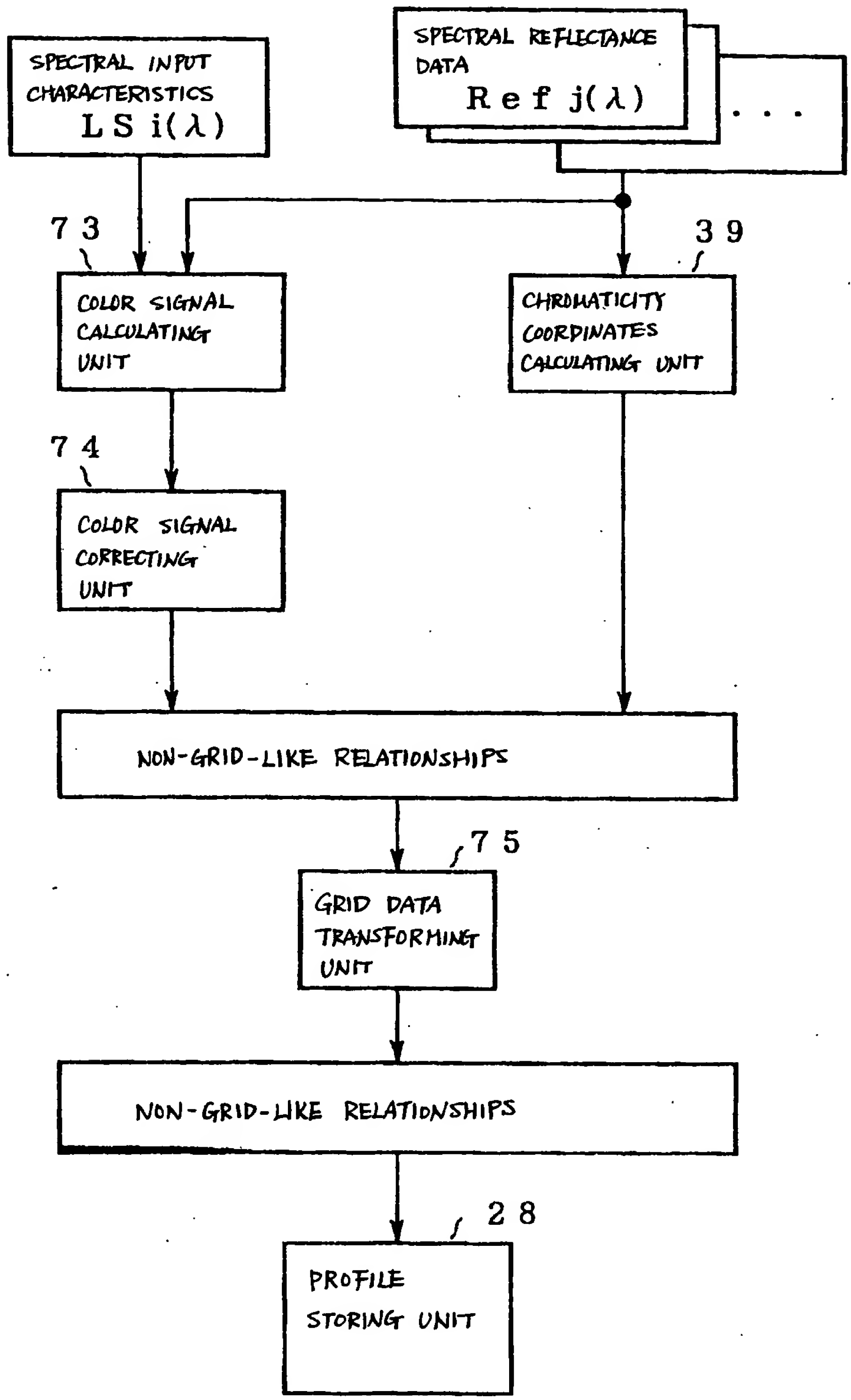

START
(S 5 1)
SELECT COLOR SAMPLES
(S 5 2)
INPUT SPECTRAL REFLECTANCE DATA
(S 5 3)
INPUT COLOR SIGNALS
(S 5 4)
ESTIMATE SPECTRAL INPUT CHARACTERISTICS
(S 5 5)
INPUT ACCUMULATED SPECTRAL REFLECTANCE DATA
(S 5 6)
CALCULATE CHROMATICITY COORDINATES
(S 5 7)
CALCULATE RGB VALUES FROM SPECTRAL REFLECTANCE DATA AND SPECTRAL INPUT CHARACTERISTICS
(S 5 8)
CORRECT CALCULATED RGB VALUES
(S 5 9)
CALCULATE PROFILE DATA CORRESPONING TO GRID POINTS IN RGB SPACE
END

FIG 16



SPECTRAL INPUT CHARACTERISTICS LS i(λ)
SPECTRAL REFLECTANCE DATA Ref j(λ)
. . .
73
COLOR SIGNAL CALCULATING UNIT
39
CHROMATICITY COORDINATES CALCULATING UNIT
74
COLOR SIGNAL CORRECTING UNIT
NON-GRID-LIKE RELATIONSHIPS
75
GRID DATA TRANSFORMING UNIT
NON-GRID-LIKE RELATIONSHIPS
28
PROFILE STORING UNIT

FIG 17

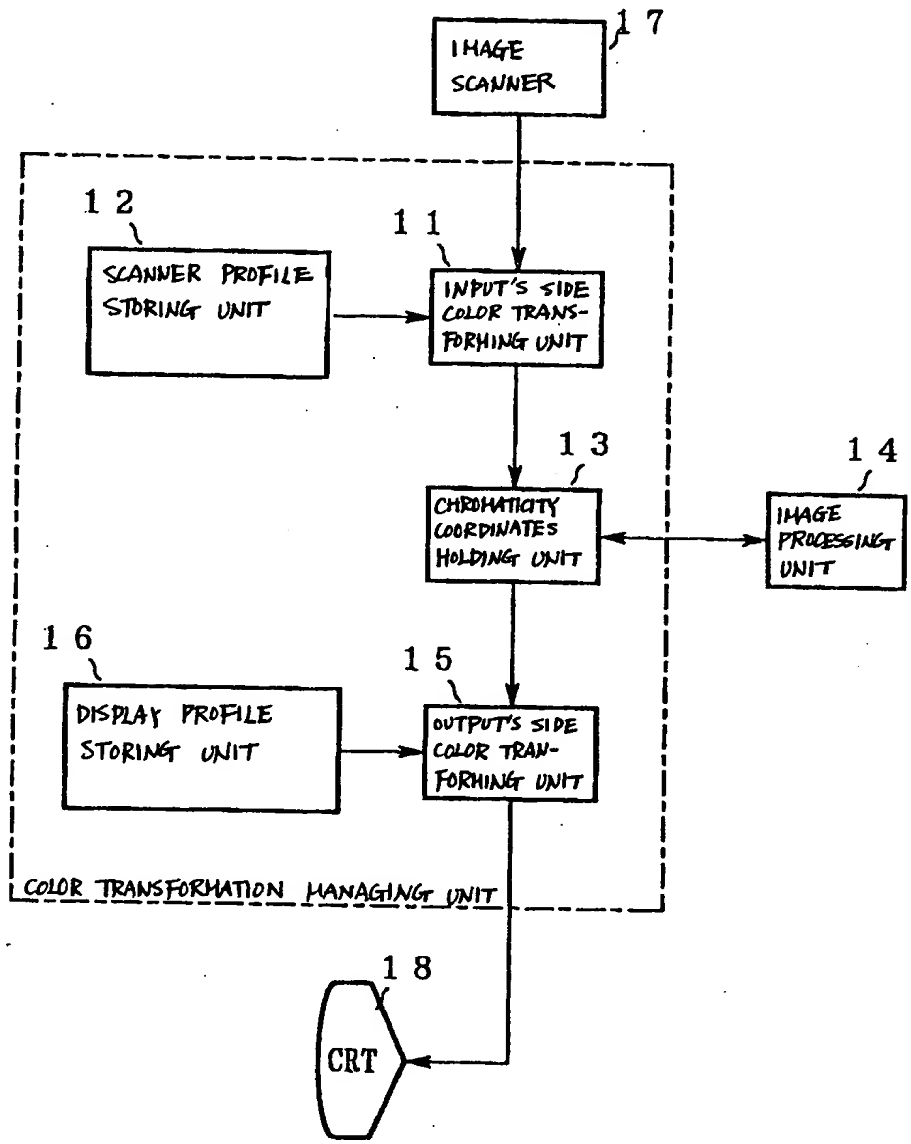


IMAGE SCANNER
17
12
SCANNER PROFILE STORING UNIT
11
INPUT'S SIDE COLOR TRANS-FORMING UNIT
13
CHROMATICITY COORDINATES HOLDING UNIT
14
IMAGE PROCESSING UNIT
16
DISPLAY PROFILE STORING UNIT
15
OUTPUT'S SIDE COLOR TRAN-FORMING UNIT
COLOR TRANSFORMATION MANAGING UNIT
18
CRT

FIG 18